COMPACT BROADBAND MICROSTRIP ANTENNA WITH DGS FOR WIRELESS APPLICATIONS

Thesis

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CERTIFICATE

This is to certify that the thesis entitled **" COMPACT BROADBAND MICROSTRIP ANTENNA WITH DGS FOR WIRELESS APPLICATIONS"** submitted in partial fulfilment of the requirements for the degree of **Master of Technology** with major in **Electronics & Communication Engineering** and minor in **Information Technology** of the College of Post-Graduate Studies, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **MR. BHARAT PANT, Id. No. 52456** under my supervision and no part of the thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation and source of literature have been duly acknowledged.

Pantnagar
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We, the undersigned, Member of the Advisory Committee of **Mr. Bharat Pant, Id. No. 52456,** a candidate for the degree of **Master of Technology** with major in **Electronics and Communication Engineering**, and minor in **Information Technology** agree that the thesis entitled**"COMPACT BROADBAND MICROSTRIP ANTENNA WITH DGS FOR WIRELESS APPLICATIONS"**may be submitted in partial fulfilment of the requirements for the degree.

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LIST OF ABBREVIATIONS

FEM	Finite Element Method
EM	Electro Magnetic
MTL	Microstrip Transmission Line
MSA	MicroStrip Antenna
EBG	Electromagnetic Band Gap
TEM	Transverse Electro Magnetic
CSRR	Complimentary Split Ring Resonator
SRR	Split Ring Resonator
TLM	Transmission Line Model
dB	Decibel
HPBW	Half Power Beam Width
HFSS	High Freqency Structure Simulator
DGS	Defective Ground Structure
CPW	Co-Planar Waveguide
VSWR	Voltage Standing Wave Ratio
PCB	Printed Circuit Board
WiMax	Worldwide Interoperability for Microwave access
WLAN	Wireless Local Area Network
IEEE	Institute of Electrical and Electronics Engineer
PCS	Personal Communication Services

VNA	Vector Network Analyzer
BWFN	Bandwidth Between First Nulls
UWB	Ultra Wideband
SMA	Sub Miniature Version A
RF	Radio Frequency
LP	Linear Polarization
CP	Circular Polarization
DSRC	Dedicated Short-Range Communication
CCTV	Closed Circuit Television Camera
PALM	Parallel Array of Linux Machine
IMT	International Mobile Telecommunication
ISM	Industrial, Scientific and Medical radio bands
HIPER LAN	High Performance Local Area Network
UNII	Unique Ingredient Identifier
UHF	Ultra High Frequency
MIMO	Multiple Input Multiple Output
UMTS	Universal Mobile Telecommunication System
LTE	Long Term Evolution
CST	Computer Simulation Technology
WiGig	Wireless Gigabit
GSM	Global System for Mobile Communication
GPS	Global Positioning System

RFID	Radio Frequency Identification
CDMA	Code Division Multiple Access
DCS	Distributed Control System
CRR	Complementary Rhombus Resonator
IDCLLR	Inter-Digital Capacitive Locked Loop Resonator

In the modern era, there are necessary requirements especially for coming generation wireless communication systems due to high speed data applications. Microstrip antenna (MSA) is a good choice in wireless communication system because of its properties as low profile, light weight, low cost and easy fabrication. (MSA) proves its utility to fulfil the requirements of modern wireless communication systems.

G.A Deschamps a well-known researcher has proposed the concept of MSA in 1953. However, the practical application of MSA has been used by Munson and Howell in 1970. MSAs that are designed for application based on band and wider bandwidth operation are very useful in case of wireless applications. MSA consists of two conducting patch and ground separated by a dielectric substrate. Different type of conducting patch like rectangular, circular, elliptical etc. is cut. To provide the high speed data services requirement of wide bandwidth is necessary. However, MSA has narrow bandwidth. Various methods have been applied to enhance the bandwidth of MSA by increasing the substrate thickness, using defected ground structure (DGS), inserting parasitic elements and use of metamaterial. By the time, recent advances in wireless communication systems, single layered broadband MSAs have attracted attention of many researchers. Different type of parasitic cuts helps to obtain broad bandwidth.

Different type of models is used to find the dimensions of the MSA based on the required operation frequency for the particular application purpose. The most common and easiest model is transmission line model (TLM). To provide the electrical energy to the antenna feeding is used for converting electrical energy into electromagnetic energy. Coaxial feed, aperture couple feed and microstrip line feed is known feeding techniques in MSA.

Institute of electronics and electrical engineers (IEEE) allocates a different frequency ranges for different applications. According to IEEE 802 standard, 2.4-2.48 GHz is assigned for WLAN, WiFi, and Bluetooth. Frequency ranges from 3.2 to 3.8 GHz and 5.2 to 5.85 GHz are assigned to worldwide interoperability for microwave access (WiMAX). There are other applications such as Personal communication services (PCS), international mobile telecommunication (IMT-2000), Future use of 5G mobile communication in India also lies in the 2 -7 GHz frequency range.

An et *al.* (2018) have developed a wideband MSA with stable gain and low profile characteristics. They have summed up four different resonant modes with different frequencies in a single structure for improving the bandwidth. To achieve the stable gain they have introduced the concept of folded walls. They have designed the antenna on FR4 substrates having the total height of 4.5 mm and the area of the substrate is 63 mm×51.2 mm. From the measurement it has been found that impedance bandwidth of the proposed antenna increases up to 58.3% in frequency range from 2.84 to 5.17 GHz. They have designed an elliptical patch on the top of the substrate and used two folded walls which acts as a reflector and generates a stable gain with an average of 5 dBi.

In the view of the above, it has, therefore, become necessary to design a MSA which has compact in size, broad bandwidth, and reasonable gain in the frequency range from 2 to 7 GHz for wireless high speed data applications. The proposed antenna consists of a rectangular patch loaded with an inverted U-shaped slot with a circular slot in the form of C-shaped which is responsible for achieving the wider bandwidth. DGS with a rectangular slot is responsible for wider bandwidth, an increase in value of return loss and to increase the gain of proposed antenna. Proposed antenna is fed by a 50 Ω microstrip feed line.

1.1 Main objectives of the thesis

The main objectives of this research work are

- To review the previous work done in MSAs for wireless application in detail.

- To study the concept of DGS along with the parasitic elements to get the enhanced bandwidth for broadband MSA.

- To design a MSA without using the metamaterial for making compact in size, broad bandwidth and corresponding good gain.

- To fabricate and measure the proposed MSA in terms of reflection coefficient, VSWR, and radiation pattern with the help of printed circuit board (PCB) prototype machine and vector network analyzer (VNA).

To achieve the objectives illustrated above, following work are carried out

i. To study previous work done in the field of MSAs for wireless applications.

ii. To study different DGS techniques and their effects on antenna performance.

iii. To design a conventional MSA suitable for wireless application with the help of transmission line model (TLM).

iv. To miniaturize MSA by using parasitic elements and DGS.

v. To enable broadband behaviour of MSA using parasitic elements and DGS.

vi. To simulate the proposed antenna using high frequency structure simulator (HFSS) and to achieve desired results with optimization technique.

vii. To fabricate the proposed antenna using PCB prototype machine.

viii. To measure the results of the fabricated antenna such as reflection coefficient and VSWR using VNA.

ix. To compare the simulated and measured results of return loss and VSWR for the proposed antenna and to compare the proposed work with earlier work done in MSA.

Therefore, an author has made an attempt to propose compact broadband MSA with DGS for wireless applications in frequency range from 2 to 7 GHz. A patch of the proposed MSA is initially designed with the help of TLM model in the frequency range from 2 to 7 GHz. The proposed antenna is then miniaturized by cutting an inverted U-shaped and C-shaped slots on the patch. DGS is then cut at the ground plane for broadband operation and gain. Parametric study and simulation work are done in HFSS software based on finite element method (FEM) used for design, simulate and visualize 3D electromagnetic (EM) problems. Different antenna parameters such asS_{11} , radiation patterns, radiation efficiency, antenna parameter and VSWR can be simulated with this software.

After the simulation, the proposed antenna design is then exported in the form of .dxf file which is used to fabricate the proposed antenna in PCB Prototype software EP-2002. Antenna parameters such as VSWR and reflection coefficient are measured with the help VNA. Gain, efficiency and radiation patterns at corresponding frequencies are simulated. Simulated results for the proposed antenna are then compared with the measured results. Results of the proposed antenna are also compared with the reference antenna as well as earlier reported MSAs.

1.2 Framework of the Thesis

Chapter 1: This chapter gives the introduction of MSA, broadband operation, wireless applications, and also the steps to be undergone in order to achieve the desired objectives set for the research work in brief.

Chapter 2: In this chapter, review of literature about earlier reported work related to the compact, multiband, and broadband antenna performed in the field of wireless applications has been discussed.

Chapter 3: In this chapter, the materials and methods are discussed for carrying out this research work. It also contains the steps which are used for the development, fabrication and measurement of the proposed antenna.

Chapter 4: In this chapter, simulated as well as measured results for the proposed antenna in terms of various parameters such as reflection coefficient, VSWR, peak gain, efficiency and radiation patterns are presented. The comparison is made between the simulated and measured results in terms of reflection coefficient & VSWR for the proposed antenna. The comparison is also made between the proposed work and the earlier quoted work.

Chapter 5: Conclusion and future scope of research work on the proposed antenna is discussed in this chapter.

To meet the objective to design, simulate, fabricate and measure the proposed antenna it is essential to understand the research work behind MSA. Here, the important work has been studied for further research in broadband MSA for wireless application field.

Munson (1974) has practically found the antenna using microstrip which forms the feed network and radiator. He has showed the four main advantage of such kind of antenna i.e. cost, performance, easy installation techniques and the low profile conformal geometry.

Howell (1975) was the first who proposed the concept of MSA. According to his research microstrip antenna has planar resonating radiator and the ground separated by thin dielectric substrate. He has discussed various types of microstrip antenna and the measuring pattern of these antennas is in UHF range through C-band.

Agrawall *et al.* (1998) has designed a planar monopole antenna by using a circular disc to achieve wideband impedance bandwidth. They have performed all the simulation on circular disc monopole (CDM) and is equal to twice the diameter of the reference disc. New configuration such as elliptical, rectangular, hexagonal disc and square monopole antenna are designed and formulated to determine the frequency corresponds to the bandwidth of the lower edge. The configurations are then related and found that elliptical disc antenna with ellipticity ratio of 1.1 gives the maximum bandwidth ranging from 1.21 to 13 GHz for VSWR less than 2.

Mak *et al.* (2000) have designed MSA with a L-shaped probe. They have obtained an impedance bandwidth of about 36% as well as gain bandwidth of 7.5 dBi in average. Two- element array fed by L-probe is now designed. By experimental results the array design suppresses the cross polarization of the proposed antenna is obtained.

Yang *et al.* (2001) have designed an E-shaped MSA which is wideband in nature. They have made two parallel slots into the patch to enhance the bandwidth.

Parametric study of the slot length, width and position has been done to achieve wider bandwidth. Bandwidth of 30.3% with frequencies of 1.9 and 2.4 GHz is obtained.

Wong *et al.* (2002) have developed a broadband circularly polarized antenna for WLAN base station which is low in cost. It comprised of corner-truncated square patch having a ground plane L-shaped, and a feed technique is single probe. They have designed an antenna considering patch's side length and the air layer substrate thickness with, 43 mm and 18 mm. An impedance bandwidth of about 30% and a gain of 8.5 dBi with a CPW feed are obtained.

Ooi *et al.* (2002) have designed an E-shaped antenna which is broadband in nature. They have obtained bandwidth of 38.41% better than any conventional MSA. To increase the bandwidth further to 44.9% washer on the probe is used.

Ali *et al.* (2003) have developed a MSA wideband in nature and is designed for (5-6 GHz) WLAN applications which can be used as a personal digital assistant (PDA), as PALM organizer. The antenna is designed on a FR4 substrate having dimensions of 28mm, 9mm and a thickness of 3 mm.
The antenna thus meets the norms of IEEE 802.11a WLAN applications (5.15-5.35 GHz and 5.725-5.825 GHz). The antenna is then tested for VSWR. The variation between the measured and computed data is quite negligible i.e. the frequencies are about the same and VSWR is in the ratio of 2:1.

Ammann and Chen (2003) have developed a monopole antenna for wireless applications. The designed antenna is having wideband characteristics. They have mentioned different techniques such as by using bevels, slots and shorting post to increase and optimize the bandwidth. To model the proposed monopole antenna method of moment (MOM) technique, amplified by the (UTD) uniform theory of diffraction is used. Maximum gain of 4.0 dBi and 5.1 dBi at 2.45 GHz and 5.750 GHz, respectively, is achieved.

li *et al.* (2003) have developed a triangular shaped patch antenna. They have used a concept of folded shorting walls to make the antenna wideband in nature. The shape of the patch is modified which results in wideband (3.5GHz-6GHz) which is approximately 54.1% bandwidth enhancement from the reference antenna. Peak gain of 5.5 dBi with a wideband is achieved.

Rafi and Shafai (2004) have developed patch antenna using V-slots and patch-via resonators for obtaining wideband. They have observed the effect of patch-via resonators on the impedance bandwidth and radiation patterns. The enhancement in the bandwidth of 58%, from 36.5% for the original rectangular patch with V-slot for the single layer case with fixed polarization throughout the bandwidth, with stable antenna gain and the cross polarization level below than -11 dB is seen.

Guo *et al.* (2005) have developed a wideband patch dipole antenna which is fabricated with microstrip structure. The antenna is simulated on Ansoft HFSS which shows the relative bandwidth enhancement of 66.7% with a VSWR less than 2. They have mounted the antenna in an infinite conducting ground plane. They have got very good gain of 7.5 dB. The antenna shows the good agreement between the simulated and measured results.

Lau and Luk (2005) have developed a circularly polarized patch antenna which is used for wireless applications and covers the band from 1.49 to 2.12 GHz and is wideband in nature. They have designed an antenna which is based on L-probe and aperture-coupling technique to feed the patch orthogonally. The substrate of thickness between the patch and ground plane is 0.1 mm and air as a material is used. For generating the circular polarization they have used the Wilkinson power combiner to the feed.

Lai and Luk (2006) have designed a patch antenna wideband in nature. Meandering probe is used for feeding which shows low cross polarization and broadside radiation pattern. They have taken the patch $0.1\lambda_0$ above the ground plane to obtain a bandwidth of 30% and a gain of 9 dBi.

Zhang *et al.* (2007) have developed a wideband monopole antenna with G-type structure, consists of two wires rectangle ring having radius of 2 mm. The antenna is designed and analyzed in the software numerical electromagnetic code (NEC) which is based on MOM. They have achieved a wideband of 510 MHz from 0.86 to 1.37 GHz with a gain of more than 2.84 dBi.

Elsasek and Nashaat (2007) have developed multiband and UWB V-shaped antenna which works for wireless applications. The antenna consists of V-shaped patch with electromagnetically coupled unequal arms in an isosceles triangular PIFA with two unequal slots, resulting in six multibands by varying different length and widths on the V-shaped and the two coupling slots. The bandwidth is thus increased by around 27% from the normal patch antenna. UWB operation is achieved by folding and shorting the walls of the triangular PIFA with a bandwidth of around 53%.

Dastranj *et al.* (2008) have developed a wide-slot antenna which is fed by a microstrip line for wideband communication. They have developed the antenna with an enhanced bandwidth of over 120% (2.8-11.4 GHz) for the return loss of -10 dB, with stable far-field radiation characteristics in the entire bandwidth with high gain and low cross polarization. They have showed that impedance matching of printed wide-slot antenna is greatly affected by feed slot combination and feed gap width. They have shown that the proposed antenna gives good return loss, far-field E-plane and H-plane radiation patterns and gain between simulated and measured results.

Lee *et al.* (2008) have developed a U-slot patch antenna which can provide impedance bandwidths increased by an amount of 20% in the microwave substrates thickness of about $0.08\lambda_0$. The antenna is fed by an L-probe. By using U-slots, two notches are introduced with broadside the pattern with the linear polarization. The antenna is designed using Zeland IE3D software's which shows the antenna impedance bandwidths (VSWR<2).

Jan and Wang (2009) have developed a wideband rhombus slot antenna with the use of parasitic strips to achieve multiband applications. They have used parasitic elements which include microstrip feed line for the bandwidth enhancement for wideband operation. The measured impedance bandwidth operates at a frequency range of 1.80 to 6.09 GHz with a center frequency of around 4 GHz which is broader than a conventional microstrip feed line antenna without using parasitic elements.
The rhombus slot is etched at FR-4 substrate having dimensions of 51.5 mm x 61mm. They have proposed the antenna for PCS, IMT-2000, and WiMax systems with good gain variations in the wide frequency range (1.80 -6.09 GHz).

Sim *et al.* (2009) have developed a dual feed, dual polarized antenna having low cross polarization and high isolation. They have used a single radiating patch and to excite the patch they have designed dual orthogonal linearly polarized mode. They have excited one mode by aperture coupled feed, having compact annular ring and a T- shaped microstrip feed line. To excite the second mode, the pair of meandering strips with a 180° phase difference is used. Both modes are designed for an operating frequency of 2.4 GHz. The bandwidth of 14% across 10-dB impedance is obtained.

Chandra *et al.* (2010) have designed a wideband antenna by using slots and having electromagnetic band gap (EBG) structures. They have then compared the proposed antenna with conventional antenna and achieved the increase in bandwidth and better suppression of harmonics than the conventional antenna. The frequency band of the proposed antenna is 5-6 GHz which is considered to be the most suitable bandwidth for wireless communication that is WiMax, WiFi outdoor, WLAN, Hiperlan/2 etc. They have achieved the gain of 4 to 6 dBi in the operating frequency band. Used substrate material is FR4.

Rathore *et al.* (2010) have developed a monopole antenna which is designed for WLAN applications. The designed antenna consists of a rectangular printed monopole antenna and defected ground plane etched on FR-4 substrate. They have developed the antenna which meets the requirements of WLAN applications and shows the dual band at 2.4 GHz and 5.2 GHz. The proposed antenna consists of an omnidirectional pattern in the both radiated E-plane and H-plane over the frequency range of 2.4 GHz and 5.2 GHz. The proposed antenna thus shows the good directivity for the frequency range of 2.4 GHz and 5.2 GHz that is 2.24 dBi and 3.87 dBi respectively. The proposed antenna shows the good agreement between the simulated and the measured results.

Papantonis and Episkopou (2011) have developed a compact dual band printed monopole antenna which is basically designed for WLAN applications. They have developed antenna which consists of two monopoles elements within the ISM 2.4GHz and 5.2/5.8 GHz frequency bands. The antenna thus provides the good bandwidth within the lower frequency and upper frequency bands that is 403 MHz (2.184 GHz-2.587 GHz) and 4004 MHz (3.880 GHz-7.884 GHz) so that it can cover the IEEE standards which are HIPERLAN, 5.5 GHz WiMAX, and 2.4/5.2/5.8 GHz WLAN. They have made the ground small such that it is suitable for almost any portable devices.

See *et al.* (2012) developed a printed diversity monopole antenna which works for WiFi /WiMAX applications. They have developed a crescent shaped radiators placed with respect to a defected ground plane. To achieve good impedance matching and low mutual coupling they have used a neutralization lines. Simulated and measured results show the antenna having a good impedance bandwidth of 54.5% (over 2.4-5.2 GHz) with a return loss < -10 dB, mutual coupling < -17 dB, and a measured gain of 2.5 dBi over the frequency range. They have shown that the antenna has a good agreement between the simulated and measured gain, radiation pattern, envelope correlation coefficient and channel capacity loss.

Luk and Wu (2012) have designed a wideband antenna which works as base station antennas for mobile communication. They have used the complementary antenna concept of combining electric dipole with a magnetic dipole. a wideband unidirectional antenna with stable frequency characteristics is obtained. The magnetic dipole antenna is realized by a triangular shaped loop antenna.

Mahlaoui *et al.* (2013) developed a dual band patch antenna for WiFi (IEEE 802.11n) applications by using a Sierpinski fractal geometry. The proposed antenna covers two wireless spectrum bandwidths, ISM 2.4 GHz and the U-NII 5 GHz. They have designed the antenna on a 1.8 mm thick substrate having dimensions of 75mm x 75mm with a dielectric constant of 2.5 and having a DGS. The antenna exhibits two frequency band, one at the frequency centered at 2.467 GHz which covers all the ISM band channels and the other at the frequency centered at 5.347 GHz in the frequency range of 4.3-6.2 GHz. They have achieved the gain of 6.21 dBi for ISM band and 7 dBi for U-NII band.

Sayidmarie and Yahya (2013) have developed a dual band crescent shape monopole antenna which works for wireless applications specifically for WLAN. The antenna shape i.e. crescent is evolved from an arc patch antenna. By optimizing the feed position along the arc they have obtained the required bandwidth for the WLAN.

They have designed the antenna which covers the frequency band of the IEEE 802.11 a/b/g (2.4-2.48 GHz, 5.15-5.35 GHz, and 5.725-5.825 GHz) using CST software package. The antenna thus simulated, provides an average gain of 2.3 dBi and 3.98 dBi in the lower and higher frequency bands, respectively.

Mok *et al.* (2013) have developed a single-layer single-patch dual-band and triple-band patch antennas by means of cutting U-slots in the patch. The methodology is applied at L-probe fed patch, the M-probe fed patch, coax-fed stacked patches, and aperture coupled stacked patches. All the given stacked patches involve complex analysis which requires complicated feed, more than one patch and more than one layer. They have applied this method to a broadband U-slot patch antenna. When they have cut on U-slot they have obtained the dual band, furthermore cut of U-slots in the broadband patch antenna gives one more additional band. The designed and fabricated antenna gives the good results with negligible changes in measured and simulated results.

Elfergani *et al.* (2014) have designed a tunable printed F-slot MIMO antenna for wireless applications. The antenna is compact and closely packed with efficient diversity. It is having a dimensions are 50 mm x 37.5 mm x 1.6 mm which is printed on FR4 substrate. They have tuned the frequency of the MIMO antenna by lumped capacitors value ranging 0.75 to 2.75 pF for a tuning range of 1.55 to 2.07 GHz. For the low mutual coupling between the radiators they add I-shaped branch to a reduced ground plane. For tuning the antenna and to achieve miniaturization varactor diode is used. So, by varying the capacitance value they have achieved the desired bandwidth with a reasonable gain.

Roshan *et al.* (2014) developed a wideband planer monopole antenna having dual band which is used for PCS, UMTS, LTE, and WiFi/WLAN applications. They have proposed the antenna having sickle shaped radiator patch, rectangular slot in ground plane and a microstrip feed line. They have simulated the results on CST microwave studio having a good operating bandwidth of 53% covering the frequency range of (1.8-3.1 GHz) and 0.5 GHz over (5.5-6 GHz) with a return loss of < -10 dB. They have achieved the gain varying from 2.6 to 4.6 dBi in desired frequency range.

Yassin *et al.* (2014) have developed a microstrip patch antenna using C-slot basically used for WiFi and WiMax applications by taking the center frequency of 3.5 GHz and 5.2 GHz. The antenna design consists of a C-slot on the patch and two parallel slit on the ground plane. The antenna designed consists of low profile, high gain and wide bandwidth for the entire frequencies. The prototype is simulated in CST microwave studio simulator with an obtained results that is return loss is -18 dB, -31 dB with a gain of 5.8 dB, 6.7 dB and bandwidth of 42 MHz, 138 MHz at 3.5 GHz and 5.2 GHz, respectively.

Shrivastava *et al.* (2014) have developed M-slot monopole antenna which is used for UWB applications. For achieving the UWB frequency they have placed an M-shaped radiator in the conventional monopole antenna, and rectangular slots in the modified ground plane. Thus, the ground plane works like a radiator which resonates at lower band of UWB.
The proposed antenna having a volume of 36 mm x 36 mm x 1.6 mm achieves good impedance matching, constant gain and a stable radiation patterns for the bandwidth of 2.38-12.40 GHz.

Sun *et al.* (2014) have developed a butterfly shaped wideband antenna generally used for wireless applications and RFID applications. To enhance the bandwidth they have taken two symmetrical quasi-circular arms and two symmetrical round holes onto the patch. The bandwidth is as good as 40.1 % is achieved. For two resonant modes at 4.15 GHz to 6.36 GHz a return loss < 10 dB is obtained. To achieve the compactness coaxial feed incorporated on a copper coated air substrate having height 5.5mm is used.

Sharma *et al.* (2015) have developed a slot loaded microstrip patch antenna working for wireless application such as wireless local area network (WLAN), and WiMax by using aperture coupled feed technique. A 'dual loop' slot is cut into the square radiator patch which gives impedance bandwidth of about 840 MHz i.e 2.37-3.21 GHz for WLAN applications and WiMax application in 2.5-2.69 GHz band. They have used HFSS for the simulation of proposed antenna. The simulated results give 2:1 VSWR bandwidth of around 30.10% with respect of mid frequency of

2.79 GHz. They have achieved a gain of 6.5 dBi for WLAN band and more than 7.3 dBi in the WiMax band with the dimension of 70 mm x 70 mm x 11.58 mm.

Wang and Chan (2015) have developed a multiband antenna used for WiFi and WiGig communications which is low cost and printed circuit board (PCB) based. The proposed antenna works both for WiFi channels (2.4/5.2/5.8 GHz) and WiGig (57-64 GHz) channels. They have developed the antenna such that when it works for WiFi range, it is based on printed monopole antenna, whereas, when antenna works at WiGig frequency band, a higher order mode patch antenna is adopted. For the feeding purpose a compact microstrip resonance cell (CMRC) low-pass filter is designed. For the WiFi frequency band this mentioned feeding technique is enabled and for WiGig frequency the monopole antenna isolates for this feeding technique. They have fabricated the antenna on standard PCB and plated-through-hole technologies. The good agreement between both measured and simulated results are shown.

Hicho *et al.* (2015) have designed a wideband low profile planar antenna using high-impedance surface which works in UHF band. They have designed a monopole antenna in a close proximity with artificial ground plane. Air gap is used between the monopole antenna and the ground plane. The antenna is designed on a PVC substrate. The major advantages of the designed antenna are low cost and large bandwidth.

Rahman *et al.* (2015) have developed a wideband planar monopole antenna for LTE, GSM, Bluetooth, WiMax, DCS, PCS, and GPS mobile terminals. They have made an antenna of volume 44.9x35.5x0.87 mm^3 placed on a substrate having dimension of 35.5mm x 75.5mm. They showed a wide -6 dB reflection coefficient bandwidth of 2.17 GHz (1.33-3.5 GHz). The antenna shows a good gain of 3.85 dBi at 2.7 GHz with a maximum directivity of 5.04 dBi at 2.7 GHz. The proposed antenna gives the radiation efficiency of 61% and 95% within the wide impedance bandwidth.

Khan and Chatterjee (2016) have developed U-slot MSA by using characteristic mode analysis and a probe feed technique is used. In the first method, the four resonating modes are utilized and in the second method U-slot MSA is designed. To enhance the bandwidth of an antenna the probe feed position is optimized. In the third and the final method the features of above methods are combined to yield better bandwidth performance.

Malekapoor and jam (2016) have designed a printed slot antenna using artificial magnetic conductor (AMC) which is wideband in nature with improved radiation performance. They have cut three unequal radiating slots at the patch. The feeding techniques used are CPW which enhances the bandwidth of the designed antenna. When an antenna without AMC is designed, a bandwidth in the range of 7.96-12.56 GHz for X- band application is obtained. With AMC the bandwidth increased upto 86.8% and the size reduction of around 62.8%.

An *et al.* (2016) have designed a dual band, dual port, linearly polarized tag antenna which is used for indoor positioning system. They have designed the antenna to work in UHF and UWB band i.e. covering 881 to 913 MHz in lower band and 2.9 to 5.35 GHz in upper band. Differential feeding technique is used to excite the ellipse shaped dipole which provides a wideband and stable radiation pattern in the upper band.

Forouzannezhad *et al.* (2017) have developed a compact antenna for near-field and far-field which works on the frequency of RFID and wireless applications. In addition to that wireless applications they have designed the antenna which utilizes inductive and capacitive near and far- field UHF and 2.4 GHz RFID applications. The antenna works at 890 to 933 MHz, GPS-L1, and 2.4 GHz. The antenna is linearly polarized radiation pattern with a gain of 1.2 to 2.5 dBi over the entire bandwidth. The proposed structure provides near E- and H- fields and simultaneous good impedance matching for far- field applications. Antenna provides the good agreement between measured and simulated gain and radiation patterns.

Sethi *et al.* (2017) have developed a hexa-band printed monopole antenna for different wireless applications which are done by inserting an L- shaped radiating elements. They have designed and fabricated the antenna to fully cover the CDMA (870-890 MHz), GSM (900-1800 MHz), DCS (1710-1880 MHz), PCS (1900 MHz), LTE-E/LTE-D (2300-2800 MHz), and WLAN (2.45/5.8 GHz) frequency bands. The antenna designed and fabricated on Rogers RT- 5880 high frequency laminate with a finite ground plane having a rectangular slot on the other side of the substrate which provides the gain of around 1.8 dB, 3.17 dB, 3.23 dB and 5.82 dB at their respective bands. They have fabricated the antenna at standard PCB technology and validated the results by measuring its S-parameters and radiation characteristics.

Hasan *et al.* (2017) developed a patch antenna having quad-band for WLAN, WiFi, WiMax applications. They have designed the antenna with H-shaped patch with an additional L-shaped stub and deformed inverted T-shaped strip having isosceles triangular shape attached to it, which resonates at 2.75 GHz, 3.34 GHz, 5.49 GHz and 6.65 GHz for a specific applications like WiFi, WiMax, WLAN, satellite communication etc. They have optimized the dimensions of the antenna up to 30 mm x 20 mm x 0.8 mm which makes the antenna low profile in nature from their reference antenna. They have calculated all the parameters like return loss, efficiency, gain, radiation pattern, surface current and VSWR of the proposed antenna in CST microwave studio. The proposed antenna has the VSWR less than 2. The radiation efficiency at 2.75 GHz, 3.34 GHz, 5.49 GHz, and 6.65 GHz is 0.998, 0.987, 0.91 and 0.96, respectively.

Jan *et al.* (2017) has developed a staircase-shaped DGS structure monopole antenna basically for UWB applications. The defected ground structure is realized as a spiral staircase pattern with an optimized antenna volume of 26x25x1.6mm^3. The antenna thus developed operates at the frequency range of 3.1 to 10.6 GHz, with a varied peak gain of 0.1 dBi to 3.36 dBi across the bands.

Iqbal and Saraereh (2017) have developed a compact reconfigurable monopole antenna for Wi-Fi/WLAN applications which works at three different resonating frequencies as the optical switch is set. When the antenna is in the state of ON, the antenna resonates at 2.45 GHz and 5.4 GHz which covers the band of 1.8-2.7 GHz (Wi-Fi) and 5.26-5.99 GHz (WLAN), respectively. When the antenna is in the state of OFF, it only resonates at 3 GHz covering the band in the range of 2.49-3.84 GHz. They designed the antenna and fabricated on an FR4 substrate having relative permittivity of 4.4, loss tangent of 0.02 and thickness of 1.6 mm. They have used PIN diode as a switch for controlling the resonating frequencies. The antenna has good gain and directivity in both states of the switch.

Boukarkar *et al.* (2017) have developed single-feed multiband patch antenna for wireless applications. They have used the shorting metalized vias bye loading those on one edge of the radiating patch for size reduction. In this they have obtained multiband by etching multiple inverted U-shapes. They have initially developed a dual band antenna and its frequency ratio is discussed furthermore. They have designed triple band and quad band antenna. The antenna is designed on a F4B substrate of dimension 40x40x1.964 mm^3 having relative permittivity and a thickness of 2.55 and 0.002 respectively. The antenna thus shows a peak gains and efficiencies vary from 1.43-3.06dBi and 42% to 74% respectively, hence, they have recommended for wireless application including point-to-point communication.

Tarbouch *et al.* (2018) have developed a microstrip patch antenna which is based on fractal geometry on the ground plane. In this, to achieve the enhance bandwidth they have combined the two miniaturization techniques to obtain the higher degree of miniaturization of a microstrip patch antenna. In the first technique they have just cut the ground plane or just reduced the ground plane size and in the second technique they have used the H-tree fractal slots in the resulting ground plane. They have designed the antenna for 5.80 GHz RFID, LTE, PCS, 2.3/2.5/3.3/3.5 GHz WiMax and for 3.6/2.4-2.5 GHz WLAN applications. The antenna consists of dimension of 47mm x 47mm x 1.6mm with a reasonable gain of 0.4 to 3.8 dB over the frequency range. They have performed the simulation in CADFEKO, MOM solver.

Fan *et al.* (2017) have developed a wideband SIW which is E-shaped and is used for Q-LINKPAN applications. The feeding method used is CPW and metallic vias for generating one more resonant mode. They have used SIW not only to generate resonant modes but also suppress the surface waves and to improve the radiation efficiency. The results are measured to give a wide bandwidth of 34.4% with an improved gain of 12.5 dBi for both short and long communication.

Lin and Chen (2017) have designed a metasurface antenna for wideband operation using characteristic mode analysis. They have designed a diamond slotted patch over a metasurface radiator which is fed by a microstrip line and a slot cut at the center of the ground plane. Characteristic mode analysis (CMA) for modeling, designing analysis and optimization is used. The overall size of the antenna is 1.78×1.78×0.07 in terms of wavelength at a designed center frequency of 5GHz. A bandwidth of 31% with a gain of 13-14.5 dBi is obtained.

Liu *et al.* (2017) have developed a both single and double layered metasurface antenna. They have designed one and two square patch array supported by a grounded dielectric substrate which forms a waveguided metamaterial. The property of metamaterial is extracted and estimated the resonating frequency of the dual mode antenna. A gain of 6.5 dBi with an increase in bandwidth of about 30% is achieved.

Tao *et al.* (2018) have developed a microstrip patch antenna by using a complementary rhombus resonator for achieving the broad bandwidth. They have introduced the additional resonance with the help of CRR to broaden the bandwidth. They have compared the antenna with and without the use of CRR and found that by using the CRR the bandwidth of the proposed antenna is dramatically increased by 200%.

Iqbal *et al. (2018)* have developed a multiple band, meandered strips connected patch antenna which is used for wireless application. The antenna works with the help of rectangular radiating elements and by using the pair of symmetrical meandered strip resonators. They has achieved the radiating efficiency of near about 85%-90% with an optimally matching of return loss less than 10 dB. They have obtainedthe adequate gain at the respective frequency band centered at 4.27 GHz, 4.85GHz and 6.45 GHz of 1.76 dB, 2.3dB and 1.45dB

Chaurasia *et al.* (2018) have developed a multiband microstrip patch antenna having small frequency ratios. They have showed six operating frequencies 1.1248, 1.1123, 1.0792, 1.1469 and 1.3254 which works for many wireless applications. They have obtained the frequency which resonates at 2.5GHz for UMTS applications, 2.812 GHz for wireless video links applications, 3.128-3.376 for WiMax, 3.872 GHz for lower C-band applications and 5.132 GHz for lower WLAN.

They have shown step by step designing of an antenna starting from the initial patch with inset feed than to introduce a dipole in the patch and the slot in the ground. Also they have introduced IDCLLR to obtain more bands in the antenna and lastly they have used SRR to get the required application based band and corresponding reasonable gain.They have analyzed the antenna in Ansoft HFSS v.15 based on FEM having dimension of 35mmx35mmx1.57mm taking dielectric constant of 4.4 and loss tangent of 0.02. Antenna resonates at 2.5 2.812, 3.128, 3.376, 3.872 and 5.132 with a gain of 2.52, 4.21, 3.78, 4.2, 3.52 and 5.08 dBi.

An *et al.* (2018) have developed a wideband MSA with stable gain and low profile characteristics. They have summed up four different resonant modes with different frequencies in a single structure for improving the bandwidth. To achieve the stable gain they have introduced the concept of folded walls. They have designed the antenna on FR4 substrates having the total height of 4.5 mm and the area of the substrate is 63 mm×51.2 mm. From the measurement it has been found that impedance bandwidth of the proposed antenna increases up to 58.3% in frequency range from 2.84 to 5.17 GHz. They have designed an elliptical patch on the top of the substrate and used two folded walls which acts as a reflector and generates a stable gain with an average of 5 dBi.

From review of literature, there is still scope of size reduction and improvement of broadbandwidth for MSA in wireless applications. An attempt has been made to propose a compact broadband microstrip antenna with DGS for wireless applications frequency ranging from 2 to 7 GHz.

The theoretical /experimental investigations have been carried out for the proposed antenna, which are distributed in the following chapters.

In this chapter, the planning methods and materials used for design, simulation, fabrication, and measurement for the proposed antenna are described thoroughly. This chapter is subdivided into six sections. In the first section, the microstrip antenna in conjunction with its parameters is introduced. The second section deals with the method of analysis used for microstrip antenna. Ansoft HFSS software is introduced and described in the third section of this chapter. This software is employed to perform the simulation work of the proposed antenna. In fourth section methodology of fabrication is described. Fifth section deals with the measurement procedure applied to the proposed antenna. In the sixth and last section of this chapter design steps that are undertaken in the style of the proposed antenna are described thoroughly.

3.1 Microstrip Patch Antenna (Balanis 1999)

Microstrip antenna consists of four main elements namely patch, substrate, ground plane, and feeding port as shown in Fig 3.1. There is patch on one side of skinny non conducting layer of a dielectric substrate and on the opposite side of the substrate, there is the ground plane. The height of substrate is taken to be relatively low(h << λ) wherever λ is the free space wavelength. Patch and ground plane are usually made from same metal. High dielectric constant is useful in reducing the dimensions of microstrip antenna. Low profile, little size and light-weight are some of the advantages of microstrip antenna that allows its integration to modern communication devices. Slim bandwidth and low gain are some of the drawbacks of microstrip antenna. Improving these characteristics has attracted the attention of researchers in era.

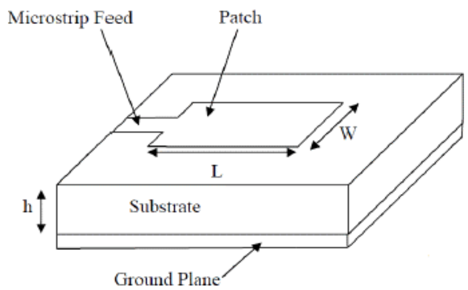


Fig. 3.1: Microstrip antenna

Choosing appropriate shape of patch is a very important consideration in extracting the precise characteristics from the antenna. Rectangular, square and circular are typically used shapes for the patch. Fig. 3.2 shows the various varieties of shapes that may be used as patch. Dielectric substrate additionally plays a very important role in performance of MSA. Dielectric constant in addition with thickness of the substrate considerably affects the performance of MSA. An increment within the bandwidth is achieved by increasing the thickness of the dielectric substrate whereas high value of dielectric constant may end up in an appreciable reduction in the size of antenna. Modification in the geometry of patch or ground modifies the performance and characteristics of the antenna that provides a scope of improvement in the field of MSA. Loads of analysis work has been done to enhance bandwidth and gain performance of MSA. There has been a big advancement in the area of MSA in recent past due to its simplicity in integration in wireless communication system.

According to IEEE customary frequency ranging from 2 to 6 GHz is allotted to wireless communication. WLAN standard operates on the range 2.4-2.48 GHz and 5.15-5.35 GHz whereas WiMAX frequency operates on the range 3.4-3.8 GHz. An antenna which is designed for these applications ought to cover these frequency bands at the same time. A compact microstrip antenna fulfil this demand because it can exhibit broadband behavior which can be enabled by some modification within the geometry of the patch or ground plane. MSA can simply be integrated to modern wireless communication system due to its compactness.

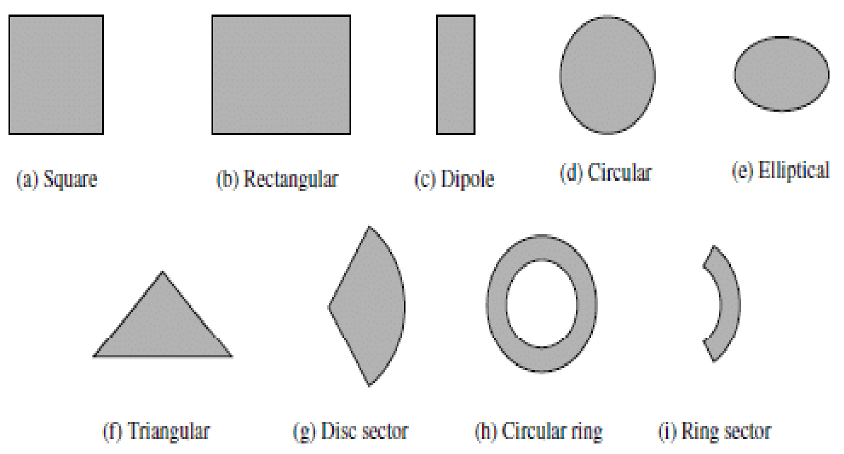


Fig. 3.2: Different shapes of patch

3.1.1 Feeding Techniques

Feeding refers to the method of providing power to the antenna that is within the style of electric current or voltage which is then regenerated into electromagnetic power in the form of electromagnetic (EM) wave. Feeding techniques are generally classified into two categories namely contacting techniques and non-contacting techniques. In contacting technique the contacting element like microstrip line is in direct contact with the radiating component i.e. patch whereas in non-contacting technique there's no physical contact of the radiating component and the feeding component. Electromagnetic coupling is employed to produce RF power in non-contacting techniques. Feeding techniques like microstrip line feed, homocentric probe feed and co-planar waveguide feed fall under contacting techniques whereas aperture coupled feed and proximity coupled feed fall under non-contacting techniques.

Microstrip line feed

A conducting strip that is of a lot smaller in dimension relative to the patch for microstrip feed line is used in order to transfer power to the patch. This microstrip feed line is directly connected to the edge of the patch as shown in Fig. 3.3. This technique provides a planar structure as feed line and patch each are placed on the same substrate. Easy fabrication and modeling makes it simplest of all feeding techniques. Typically an inset cut can be employed to match the impedance properly. Further matching element is not needed in this technique. Increasing the thickness of the substrate generally causes spurious feed radiation and surface wave radiation that eventually leads to reduction of the bandwidth of the antenna so degrading the antenna performance.

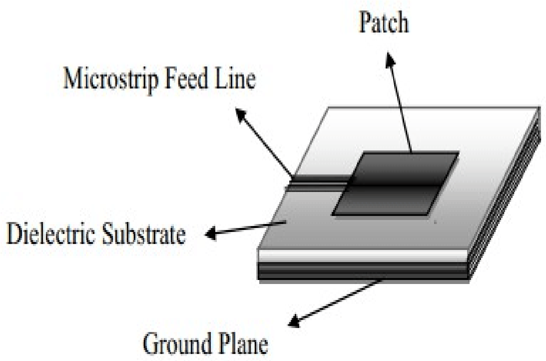


Fig. 3.3: Microstrip line feed

Coaxial probe feed

A coaxial line is employed in this feeding technique. The inner conductor of the coaxial line is connected to the radiating patch and the outer conductor is connected to the ground plane and therefore, the coaxial line passes directly through the substrate. Fig. 3.4 shows the coaxial feed. This is often conjointly a widely used feeding technique that is also referred to as probe feed technique. In this feeding technique coaxial line may be placed in any location on the patch area in contrast to microstrip line feed during which feed-line is solely be connected to the edges. Impedance matching is comparatively simple in this technique. Fabrication and modelling of this technique is easy.

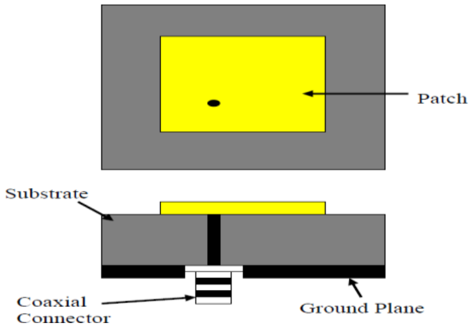


Fig. 3.4: Coaxial probe feed

Co-planer waveguide feed

Co-planer waveguide (CPW) feed consists of a metallic strip that is surrounded by two electrodes on the same plane of dielectric substrate. Therefore this feeding technique is independent of the height of dielectric substrate that is extremely useful in enhancing the bandwidth of antenna. CPW feed is compatible with the fabrication of monolithic integrated circuits as both radiating patch and ground are placed on identical plane. Radiation losses are relatively low during this feeding technique. Fig. 3.5 shows the schematic of co-planer waveguide feed.

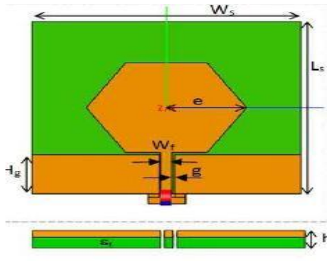


Fig. 3.5: Co-planer waveguide feed

Aperture coupled feed

This feeding technique is employed in layered structure which makes it tough to fabricate. An aperture is essentially a slot that is employed for electromagnetic coupling between the patch and feed-line as shown in Fig. 3.6. Patch is usually placed on the top of upper substrate and feed-line at the bottom of lower substrate. Patch and the feed line are separated by the ground plane. A slot is engraved on the ground plane that is responsible for the coupling. Upper substrate is usually of low dielectric constant whereas bottom substrate is of high dielectric constant. Shape and size of the aperture is optimized properly because it is crucial in deciding the amount of coupling between patch and feed-line.

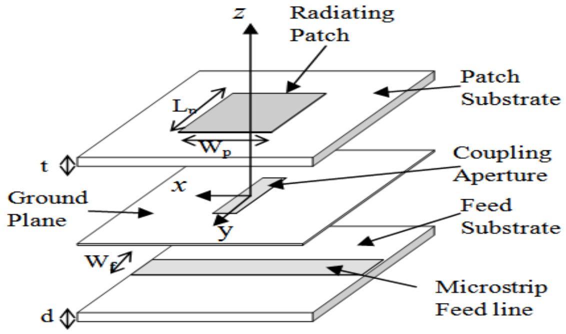


Fig. 3.6: Aperture coupled feed

Proximity coupled feed

This technique is also referred to as electromagnetic coupling scheme and the layered structure consisting two dielectric substrates is employed. Fig. 3.7 shows the structure of proximity coupled feeding technique. Radiating patch is placed on the top of upper substrate and feed-line is placed in between the two substrates. Spurious feed radiation is eliminated and consequently a high bandwidth is achieved. There is an increment in the thickness of the structure owing to the layered characteristic.

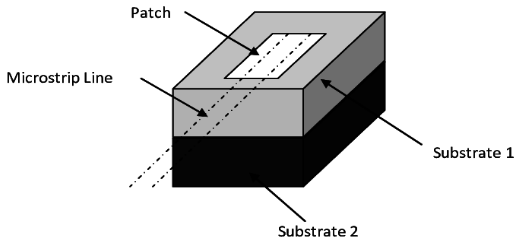


Fig. 3.7: Proximity coupled feed

3.1.2 Antenna parameters (Kraus,1998)

Antenna parameters have to be defined so as to characterize antenna performance. Antenna parameters are changed to desired value consistent with the application specifications as different applications need different values of antenna parameters. Some of the necessary parameters are radiation pattern, gain, efficiency, directivity, impedance, bandwidth and antenna polarization that are explained here.

Radiation patterns

Radiation properties of antenna are depicted diagrammatically or with the assistance of mathematical function that is termed as radiation pattern. Radiation pattern is usually taken as a function of space coordinates. Radiation properties comprise radiation intensity, field strength and directivity. Radiation patterns are usually drawn in the form of power pattern and field patterns that are normalized with reference to the maximum value.

- Field pattern is a graphical representation of the magnitude of far field values i.e. E and H which are denoted as a function of angular space.
- Power pattern represents the graph of the square of the electric and magnetic field that is denoted as a function of angular space

Radiation patterns are used to categorize the antennas into following categories:

- **Isotropic antenna:** Isotropic antenna is, by assumption, a hypothetical radiator that radiates equally in all the directions. It is assumed that there are no losses in case of this antenna making it ideal and therefore the practical realization of this radiator is not possible. Owing to its ideal behavior isotropic antenna is taken as a reference in describing the directive properties of other antennas.
- **Directional antenna:** Directional antenna is a kind of antenna that has greater radiation in some particular direction. Directional antenna is used for the applications where we need relatively more directivity. Horn antenna, Yagi-uda antenna and Log-periodic antenna are some examples of directional antenna.
- **Omnidirectional antenna:** For some antennas we get a directional pattern for some plane and non-directional pattern for some other plane. This kind of antenna is termed as omnidirectional antenna. Maximum radiation is obtained for broadside direction whereas no radiation appears at the ends of the dipole. Slot antenna and

dipole antenna are some example of omnidirectional antenna.

Reflection coefficient

Magnitude of the reflection coefficient ranges from 0 to 1. It shows the amount of power reflected back by the antenna. In order to minimize the losses in the antenna input impedance of the antenna is kept nearer to characteristic impedance of the antenna. S_{11} Parameter (Γ) is used to denote the reflection coefficient.

$$\Gamma = \frac{Z_A - Z_0}{Z_A + Z_0} \qquad (3.1)$$

Where Z_A is the input impedence of transmitting antenna and Z_0 is the characteristic impedence of transmitting antenna.

Return Loss

Return loss can be defined as:

$$\text{Return Loss} = -20\log \Gamma \qquad (3.2)$$

Return loss plays an important in characterizing the antenna performance.

Voltage standing wave ratio (VSWR)

VSWR is another significant characteristic that characterizes the performance of an antenna. In general, it is defined as the ratio of peak amplitude of standing wave voltage to the minimum amplitude of the standing wave voltage. Mathematically, VSWR is dependent on the magnitude of reflection coefficient and is denoted by:

$$VSWR = \frac{1+\Gamma}{1-\Gamma} \qquad (3.3)$$

VSWR ranges from 1 to ∞

$$\text{VSWR} = 1 \text{ (perfect matching)} \qquad (3.4)$$

$$\text{VSWR} \neq 1 \text{ (No matching)} \qquad (3.5)$$

Directivity

Directivity denotes the radiation in any particular direction. It is a measure of how directional the antenna is. If the direction is not known then the direction of maximum radiation is taken. Mathematical formula describes it as the ratio of maximum radiation intensity to the average radiation intensity. Directivity of an isotropic antenna is 1 as it radiates uniformly and equally in all the directions. The average radiation intensity of an antenna is obtained by dividing total radiated power by the factor 4π.

$$\text{Directivity} = \frac{\text{Maximum Radiation Intensity}}{\text{Average Radiation Intensity}} \tag{3.6}$$

Gain

Gain is another important parameter that describes the performance of antenna. Directivity as well as radiation intensity are taken into consideration in order to calculate the gain of an antenna. Gain of the antenna is defined as the ratio of radiation intensity to a particular direction to the radiation intensity that would be obtained if the input power were radiated equally and uniformly in all directions i.e. isotropic.

$$\text{Gain} = 4\pi \frac{\text{Radiation Intensity}}{\text{Total Input Power}} \tag{3.7}$$

Typically the measure of gain is taken relatively with a reference antenna i.e. ratio of power gain in particular direction to the power gain of reference antenna. Typically a horn or dipole antenna is taken as reference antenna. Gain is measured in dB or dBi. The unit dBi is considered when we take isotropic radiator as reference. As we know isotropic radiator is hypothetical and has a gain 1 dB and dBi are considered as equal.

Bandwidth

Bandwidth is defined as a range of frequencies for which the antenna parameters such as reflection coefficient, input impedance or field patterns are taken into some specified limits. For an antenna, bandwidth is represented in terms of reflection coefficient S_{11}. And by conventional point of view it should be less than -10 dB as shown in Fig. 3.9.

$$\text{Bandwidth} = \frac{f_u - f_l}{f_c} \times 100 \tag{3.8}$$

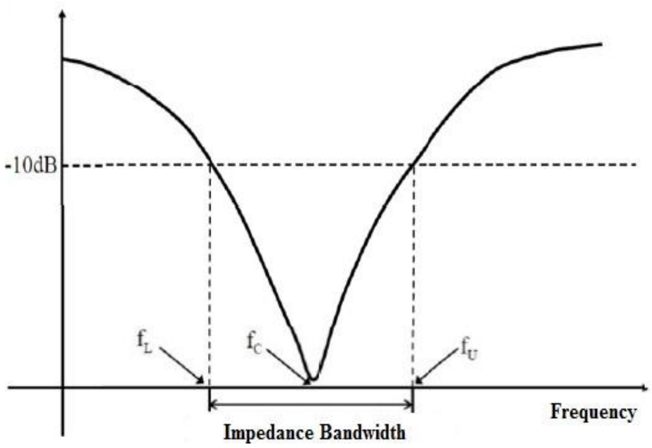


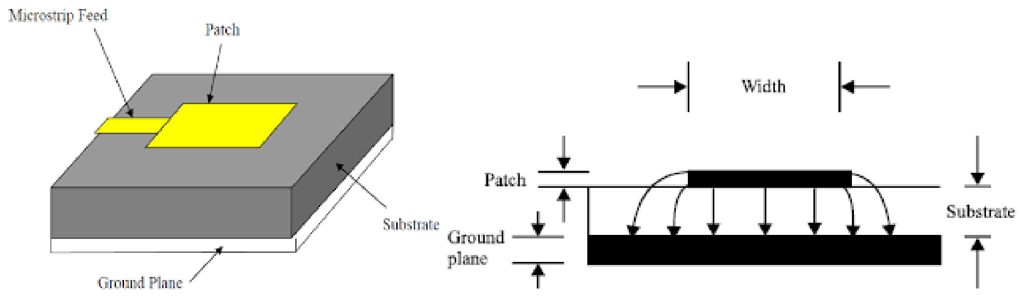
Fig. 3.8: Bandwidth of an antenna

3.2 Methods of analysis

Microstrip antenna study is based on the equivalent magnetic current distribution on and around the edges of the patch and can be categorized as a planar component for analysis. There are three models that are quite prominent to analyze the microstrip antenna i.e. TLM, Cavity model and Full wave moment (multiple network model) method. The proposed antenna employs only the TLM that is why only TLM is discussed underneath in depth.

3.2.1 Transmission line model (TLM) (Garg*et al.* 2002)

The very basic among the three is TLM which provides a good physical perspective of the antenna and is an easy to model and understand concept. In this, microstrip antenna is represented by two rectangular slots of width 'W' and height 'h' separated by the distance 'L'. The antenna is considered as a non-homogeneous line of two dielectrics i.e. substrate and air.



(a) **(b)**

Fig. 3.9 (a) Microstrip line and (b) Fringing phenomenon

As shown in Fig. 3.10 (b) the electric field line does not confine in the substrate completely due to surface tension and some electric field lines bulged out in a small portion of air. Due to different phase velocity of the air and the dielectric substrate microstrip line doesn't support pure TEM mode of operation. Therefore, the dominant mode of operation here is quasi-TEM mode. This mechanism is termed as 'Fringing'. After taking fringing effect into account the value of relative permittivity (ε_r) is modified to effective relative permittivity (ε_{reff}).

To calculate the actual length and width of the patch following equations are used

i. **Width of the patch**

$$W = \frac{C}{2f_r}\sqrt{\frac{2}{\mathcal{E}_{reff}+1}} \quad (3.9)$$

Where "c" is the speed of light and "f_r" is the operating frequency or resonant frequency of microstrip antenna.

ii. **Effective dielectric constant**

$$\mathcal{E}_{reff} = \frac{\mathcal{E}_r+1}{2} + \frac{\mathcal{E}_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right) \quad (3.10)$$

iii. **Effective length**

$$L_{eff} = \frac{C}{2f_r\sqrt{\mathcal{E}_{reff}}} \quad (3.11)$$

iv. **Length extension (ΔL)**

$$\Delta L = 0.42h\frac{(\mathcal{E}_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\mathcal{E}_{reff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad (3.12)$$

v. **Actual length of the patch**

$$L = L_{eff} - 2\Delta L \quad (3.13)$$

vi. **Ground plane dimensions**

$$L_s = 6h + L \quad (3.14)$$

$$W_s = 6h + W \quad (3.15)$$

3.3 Ansoft HFSS simulation tool (Ansoft HFSS user's manual, 2005)

FEM is a form of numerical technique which is used to perform finite element analysis (FEA) of any physical problem. Partial differential equations are used to provide this structural analysis. In FEM a large problem is then categorized into much smaller parts which are called finite elements. These finite elements are afterwards modeled and solved into simple equations individually and are then recombined in order to get the solution of large problems. A complex problem becomes relatively simpler by using this technique. The technique used includes a mesh generation technique and FEM algorithm.

Simulation of the proposed antenna is done by using HFSS. HFSS is a full wave FEM based electromagnetic field solver that is used to solve complex 3D problems. Windows graphical user interface (GUI) is used to run this software. Visualization solution and simulation of electromagnetic problem becomes very easy by using this software. HFSS is famous among RF and Microwave design engineers for modeling and solution of RF and microwave devices.

The basic mesh element used in HFSS is Tetrahedron. It implements Maxwell's equations at each node in order to obtain the solution of problem. These problems are solved within minutes by this approach. Antenna parameters such as S_{11}, gain, radiation patterns and efficiency can be obtained with the help of this software.

3.4 Mode of Fabrication

After finalizing the designing and simulation of proposed antenna, next and step is to fabricate the proposed antenna in a planar 2D model. HFSS software is used for designing and simulation of the proposed antenna. Optimized Simulated results are being saved to compare the simulated and the measured results. Fabrication can be carried out in various steps. Initially, HFSS software is used to export the simulated results in drawing exchange format (.dxf) file. That (.dxf) file is then imported to Gerber file which is opened with the help of PCB prototype software. The PCB prototype software is tuned with to the PCB prototype machine EP2002 to fabricate the antenna in a copper sheet with desired substrate as shown in fig.. The PCB prototype machine is an automated machine that is software controlled in which different drill bits (having size in mm) are used for different purposes. The process of fabrication involved following four steps i.e. fixed point drilling, surface inspect, engraving and routing. Each step is carried out with the help of different drill bits. These drill bits are changed manually as per the need of the steps. Primarily, to fix the location where the proposed antenna is going to fabricate drill fixed position command is used. After that, to check the level of copper in a substrate and to smoothen the surface, surface inspect is used. A FR4(Fire or Flame Retardant 4) substrate sheet coated with copper on both sides is taken. For designing, the patch is engraved on one side of the copper coated substrate sheet. The sheet is turned around with the help of fixed positions. Design of ground plane is engraved on the other side of the sheet. After the complete design of patch and ground on both sides of the sheet, the routing path is given to the boundaries of engraved design of the proposed antenna. The PCB prototype machine then routes the antenna from the substrate sheet. Routing is a procedure of taking out the antenna from the substrate sheet. After the routing process the sub miniature version A (SMA) connector is soldered to the feed position. The connection of the SMA connector should be done very carefully such that no extra metal other than the fabricated design will remain which can affect the impedance matching of feed.

After the completion of fabrication process, measurement of the proposed antenna can be done with the help of VNA in which the parameters like reflection coefficient S_{11} (dB) and VSWR are measured. Initially the frequency range of operation is given to the VNA. Then VNA is calibrated manually (open, short and load) in order to nullify the cable loss and other losses with the help of calibration kit and the fabricated antenna is connected to the cable to measure the parameters i.e. reflection coefficient S_{11} and VSWR. The complete process of designing, fabrication, and measurement is shown in flow chart given below Fig 3.11.

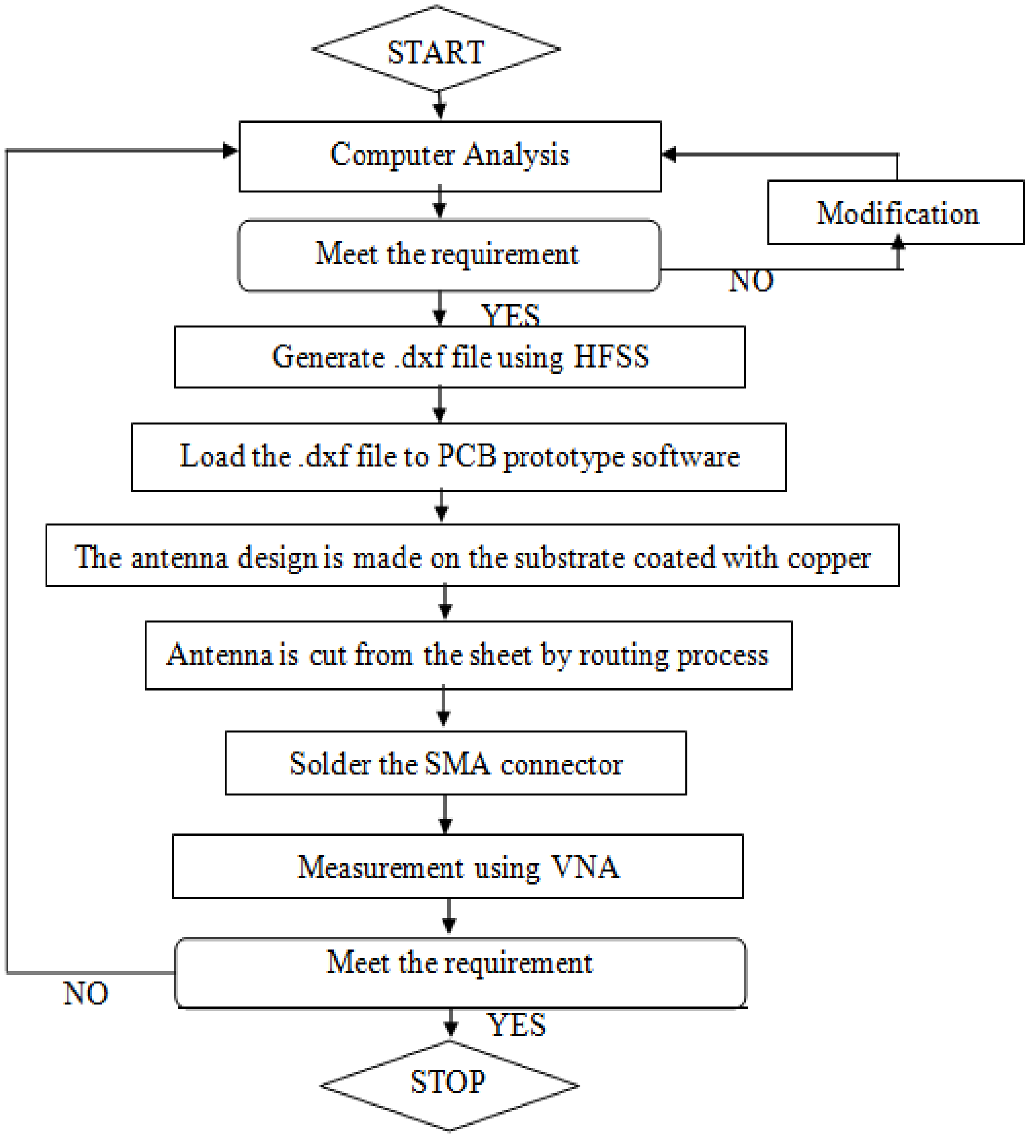


Fig. 3.10: flow chart of designing and fabrication of the proposed antenna

3.5 Antenna measurement

After fabrication the next step is the measurement of the antenna parameters. The parameters must show the good agreements with the results obtained by simulation of the antenna. There are two methods of measurements i.e. passive measurement and active measurement.

Passive measurement: In this type of measurement method the host device is inactive by which it is called as passive measurement. An external signal generator is used to measure the Parameters such as reflection coefficient, VSWR and bandwidth. Vector network analyzer (VNA) is used for this measurement as shown in Fig. 3.12.

Active measurement: In this, test antenna is kept in contact with the working device. Parameters are obtained with respect to a reference antenna. it is generally used for the measurement of gain, radiation pattern, and radiated power.

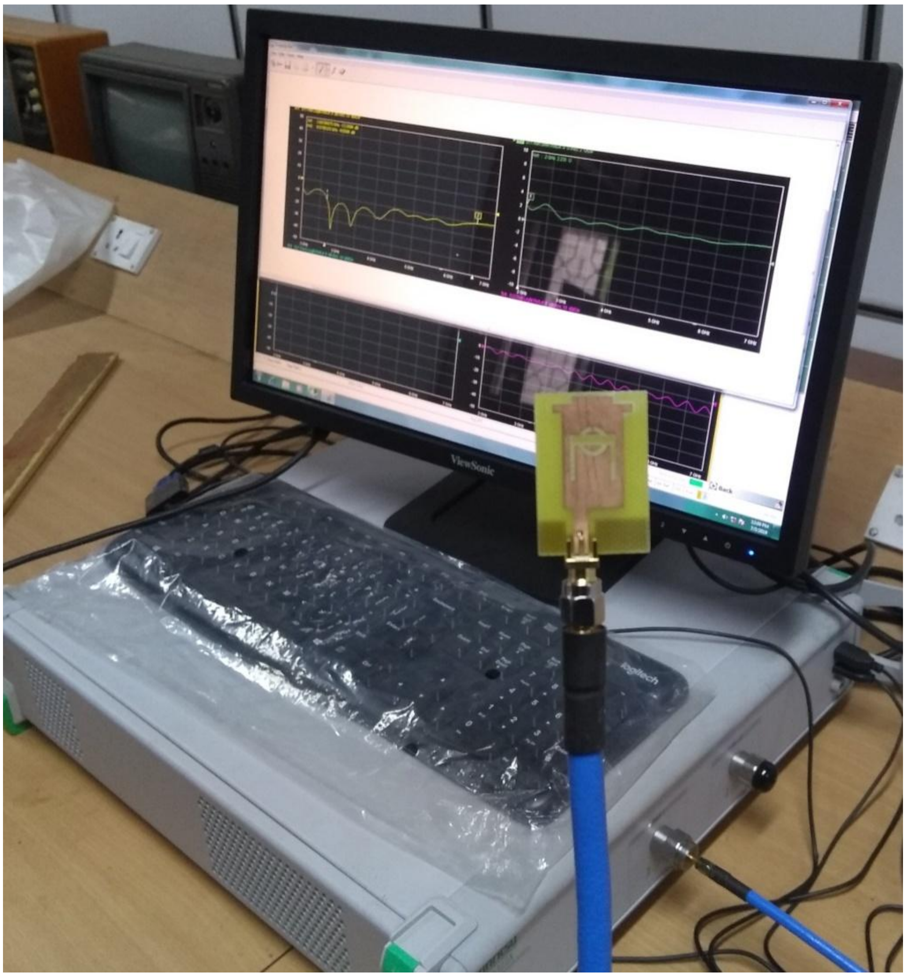


Fig. 3.11 : Measurement of the proposed antenna

3.6 Development of the proposed antenna

A compact broadband microstrip patch antenna with DGS has been proposed for all wireless applications in the frequency range from 2 to 7 GHz. The microstrip line feed is used in this proposed antenna. The center or resonant frequency is taken as 4 GHz. Initially, a conventional patch antenna is designed and simulated by using TLM and HFSS software, respectively. Ground plane is then reduced to achieve the wideband characteristics. Parametric studies have been carried out for both the patch and ground as to make the antenna compact and broad bandwidth with reasonable gain.

An inverted U-slot is cut on the patch for wider bandwidth at higher frequency i.e. 5 to 6.5 GHz. Another C-slot is then combined with the inverted U- slot to achieve the bandwidth from 2.7 to 6.5 GHz for covering entire frequency range. To improve the gain of the proposed antenna DGS is used. One simple rectangular slot is cut on the reduced ground for further improving the gain. Thus, the proposed antenna is fabricated and measured with help of PCB prototype machine EP (2002) and VNA, respectively.

There are merely three stages involved in design of the proposed antenna.

- A conventional rectangular MSA with/without reduced ground is designed, simulated and optimized.
- An inverted U-slot and C-slot are cut on the patch to achieve widerband in the frequency range from 2-7 GHz.
- A rectangular slot is cut on the reduced ground to achieve increased gain.

3.6.1 Conventional rectangular antenna design with/without reduction in ground plane and modification of feed line

A conventional rectangular MSA is initially designed by using TLM at operating frequency of 5GHz for without reducing the ground plane. Then its dimension is optimized with the help of parametric studies with microstrip line inset feed. For conventional MSA, the length (L_g) & the width (W_g) of the ground are found to be 35 mm & 35mm, and the length (L_p) & the width (W_p) of the patch is found to be 13.746 mm &18.257 mm. The conventional antenna is designed on a FR4 substrate having dielectric constant of 4.4 and loss tangent of 0.02 with dimension L_s=W_s=35mm and substrate height (h) is 1.6 mm along with loss tangent of 0.02. The conventional rectangular MSA is shown in Fig. 3.12(a) and the reflection coefficient vs frequency are shown in 3.12(b).

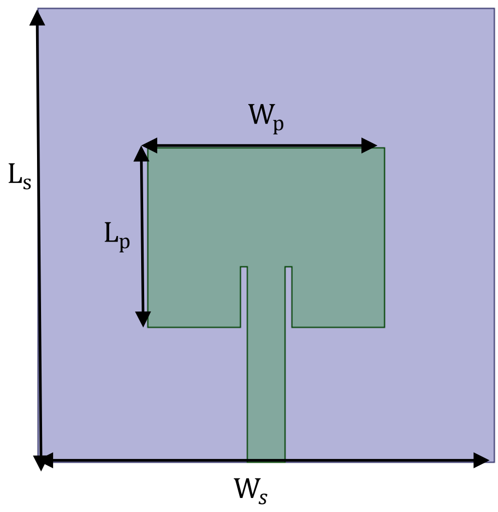


Fig. 3.12 (a):Conventional rectangular MSA

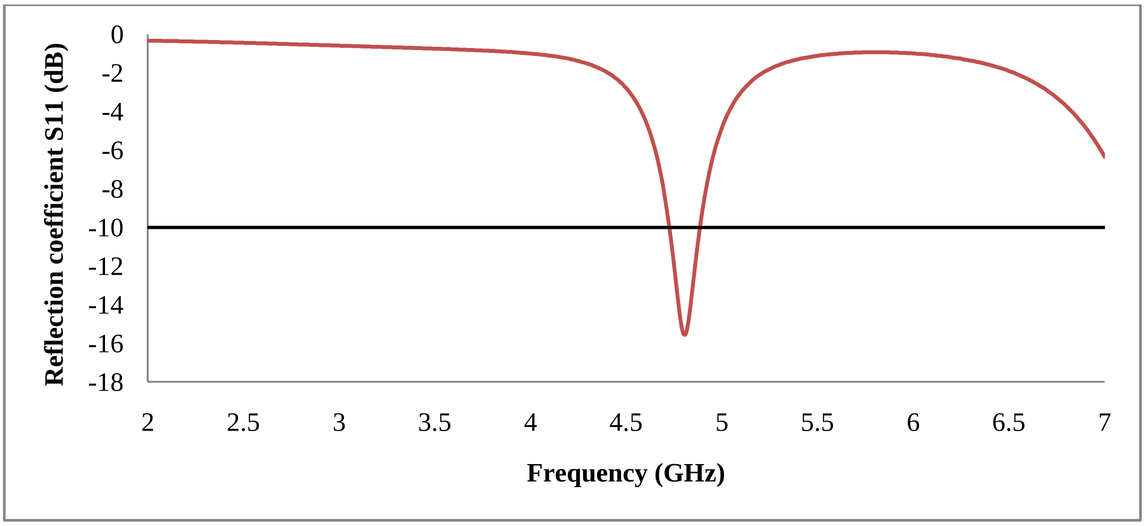
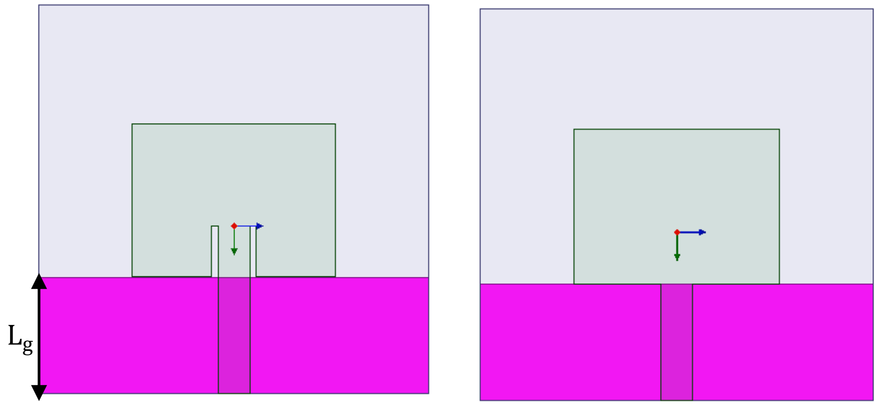


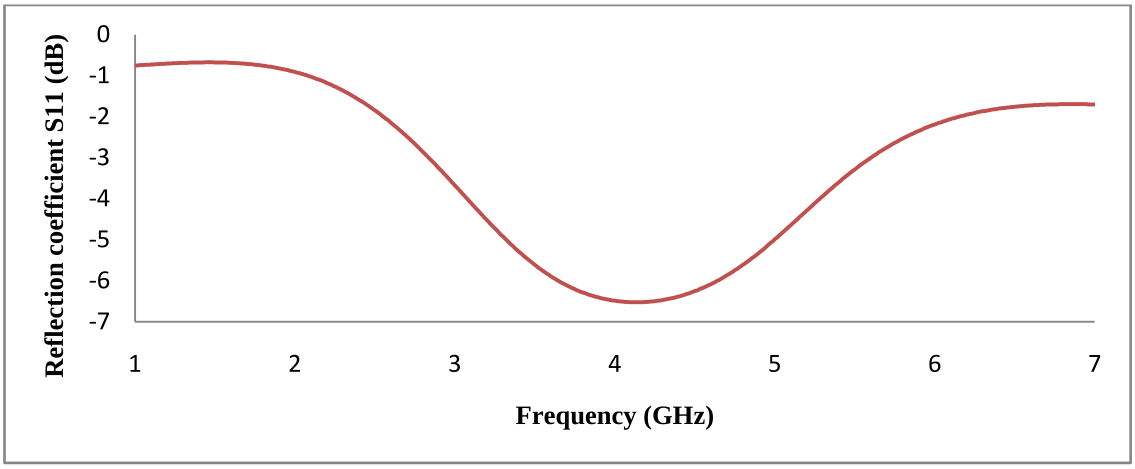
Fig. 3.12 (b): Reflection coefficient Vs frequency

It is seen from the Fig 3.12 (b) that has bandwidth of conventional rectangular MSA is found to be 160 MHz with reflection coefficient of S_{11}< -10 dB in frequency range from 4.73 to 4.89 GHz. This bandwidth is very less and it is, further, increased.

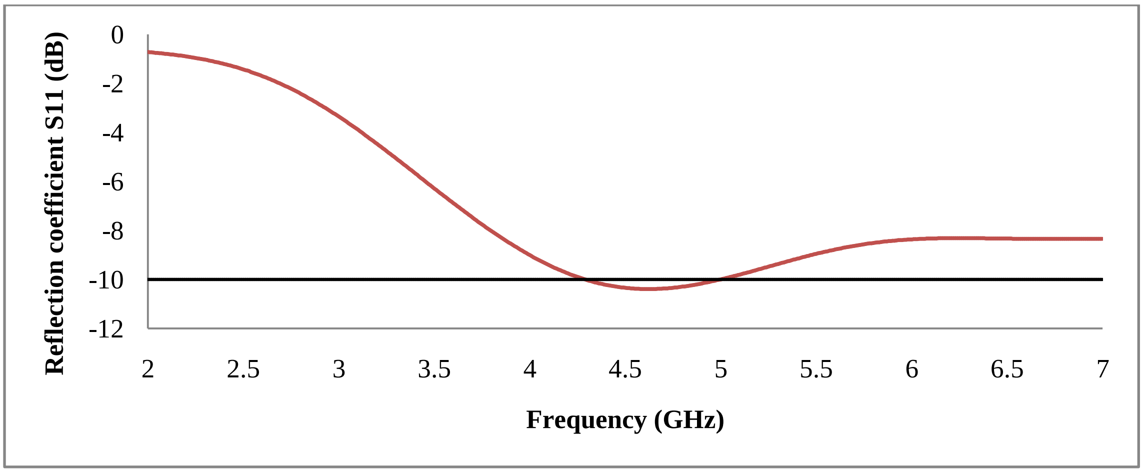
To further increase the bandwidth, the conventional MSA is converted into a monopole MSA by reducing the length of the ground (L_g) up to 9 mm. The reduction in ground plane of monopole MSA with microstrip inset line feed and microstrip line feed are represented as shown in Figs. 3.13 (a) & 3.13 (b), respectively. Fig. 3.13 (c) and (d) show their reflection coefficients vs frequency graphs.



(a) (b)



(c)



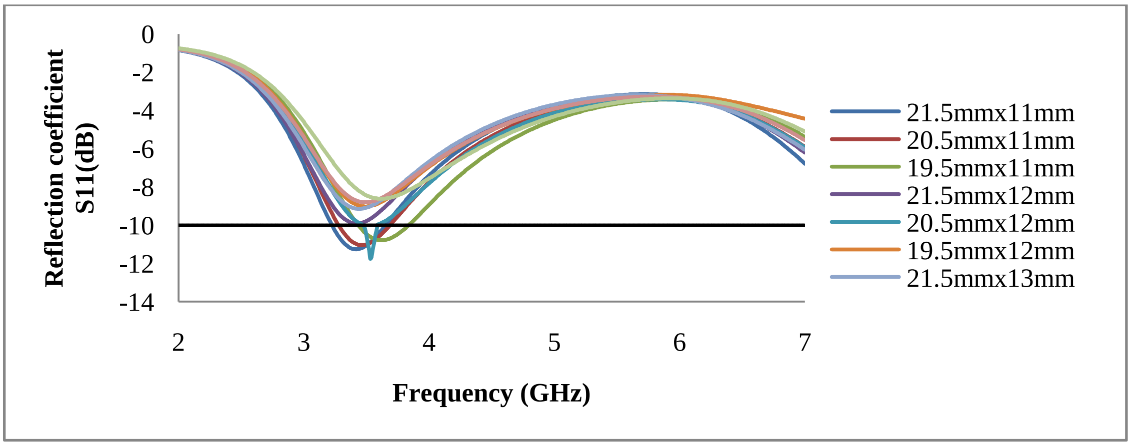
(d)

Fig. 3.13: (a) Reduced ground for monopole MSA with inset feed, (b) Reduced ground for monopole MSA with microstrip line feed, and (c) Reflection coefficient for monopole MSA with inset feed, (d) Reflection coefficient of the monopole MSA with microstrip line feed.

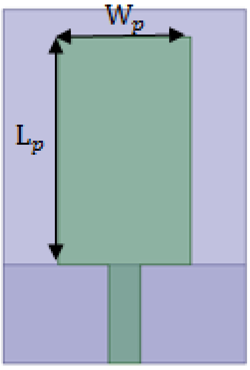
It is observed from Fig. 3.13 (c) that the monopole MSA with inset feed does not work. However, the bandwidth of the monopole MSA with microstrip line feed is obtained as 600 MHz in the frequency range from 4.4 to 5 GHz as indicated in Fig. 3.13 (d). Therefore, the MSA with microstrip feed line is, further, optimized for miniaturization and enhancement of bandwidth.

Optimization of the patch for proposed antenna

In order to miniaturize and to enhance bandwidth for the MSA with microstrip feed line, parametric study is carried out. Primarily, the length and width of the patch for the proposed antenna are optimized for all the possible values from 19.5 mm×11 mm to 21.5 mm ×13 mm and obtained as 20.5 mm×12 mm for the reflection coefficient of -12 dB as indicated in Fig.3.14 (a). By reducing the ground plane the operating frequency is shifted from 4.81 to 4.5 GHz. Further, miniaturization of the patch takes place for considering new operating frequency at 4.0 GHz. Substrate length (L_s) and width (W_s) are determined as 32 mm×22 mm using TLM.



(a)



(b)

Fig. 3.14: (a) Reflection coefficient Vs Frequency for optimization the length (L_p) & the width (W_p) of the patch and (b) Optimized dimensions of the patch

As seen from the above Fig. 3.14 (a), there is no significant effect on reflection coefficient because of varying the width of the patch whereas length of the patch is varied; the resonant frequency is shifted from 5 GHz to near about 3.6 GHz.

Optimization of length & width of microstrip feed line and offset feed

To feed the maximum power to the antenna, proper impedance matching is required. For this, as length & width of the patch, the length & width of substrate are kept constant, the length and width of the microstrip feed line at center of the patch are varied for the values from 8.9 mm× 2.75 mm to 9.2 mm × 3.05 mm. The optimized values of length (L_f) and width (W_f) for microstrip feed line are determined to be 9 mm × 2.85 mm for the reflection coefficient of -11 dB as shown in Fig. 3.15 in order to achieve proper impedance matching.

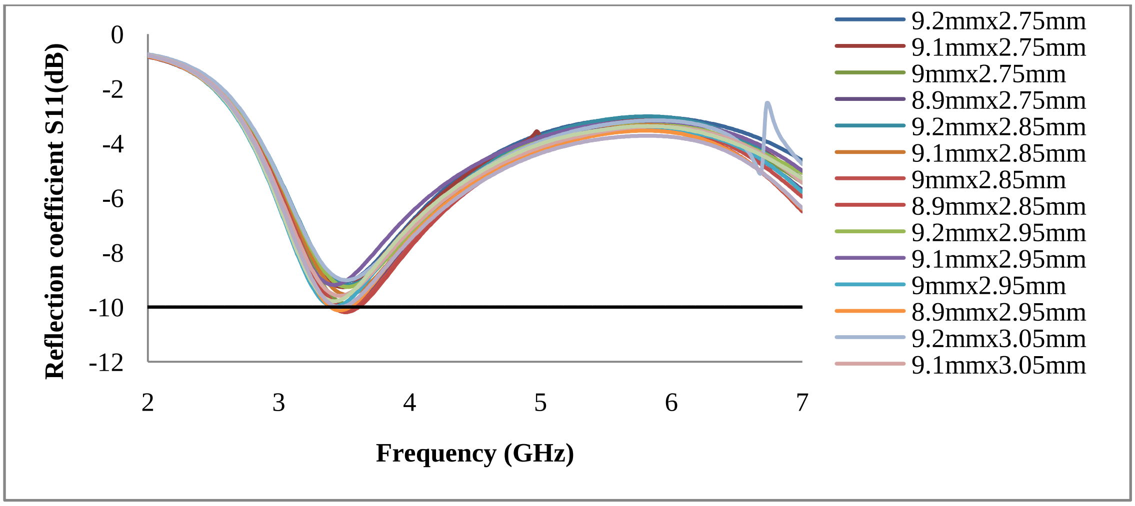
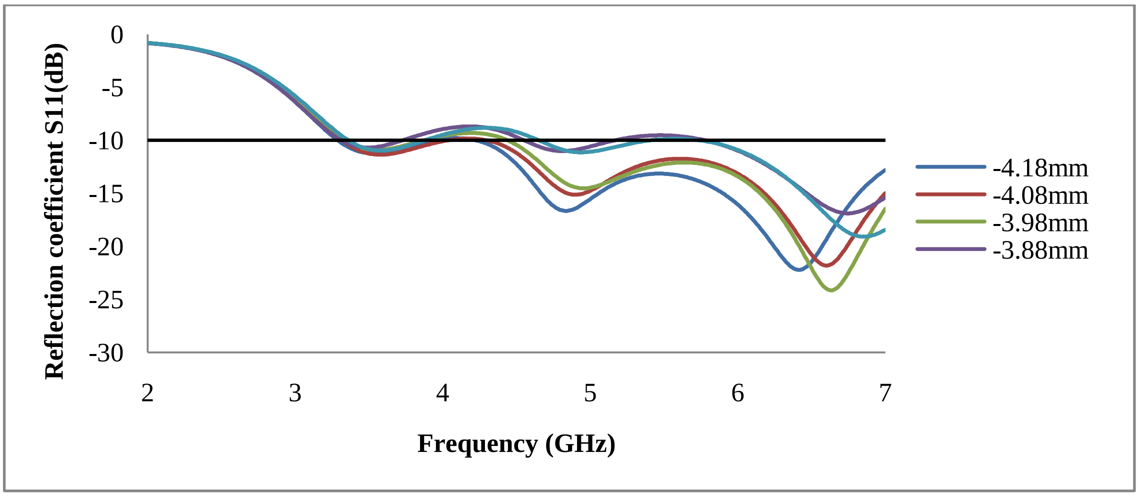
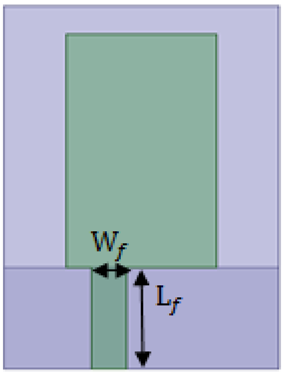


Fig. 3.15: Reflection coefficient Vs frequency for optimization of the length (L_f) and width (W_f) of the microstrip feed line

Keeping the length and width of the feed line constant, the position of feed line is varied from center of the patch to left side of the patch for the values from -3.88 to -4.18 mm as shown in Fig. 3.16 (a). It is seen that the optimized values of position of feed line are obtained as -3.98 mm from the center to left of the patch at reflection coefficient of -25 dB. Fig.3.16 (a) shows the parametric study for the feed offset and Fig.3.16 (b) shows the modified offset feed.



(a)



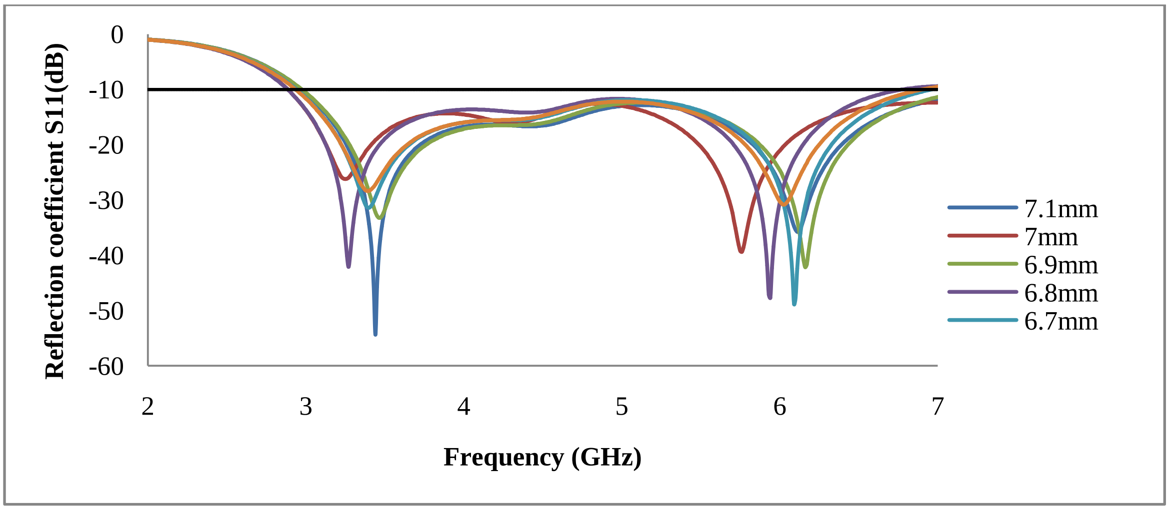
(b)

Fig. 3.16: (a) Optimization of position of feed line & (b) MSA with feed offset

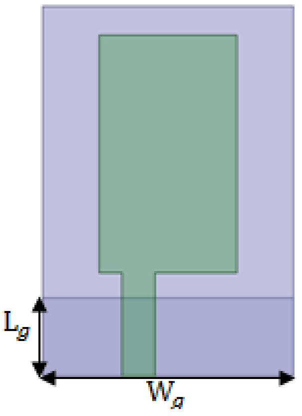
No effect of variation in position of feed line from centre to right is observed. The bandwidth of 2600 MHz in the frequency range from 4.5 to 7 GHz at reflection coefficient of -25 dB is achieved in Fig. 3.16 (a)

3.6.2 Optimization of dimension of ground plane

After the optimization for dimensions of the patch, the substrate,& the feed line and the position of feed line, these dimensions and positions are now kept constant and the next step is to optimize the dimensions of the ground plane to achieve further enhancement of bandwidth. To enhance the bandwidth, the dimensions of the ground plane are varied for the values from 6.6 mm×22 mm to 7.1 mm×22 mm as shown in Fig. 3.17 (a) from which the optimized length (L_g)and width (W_g) of the ground plane are, thus, obtained as 6.8 mm×22 mm. It is also seen from the figure that the bandwidth of 3870 MHz in the frequency range 3- 6.8 GHz for the reflection coefficient of -48 dB is achieved.



(a)



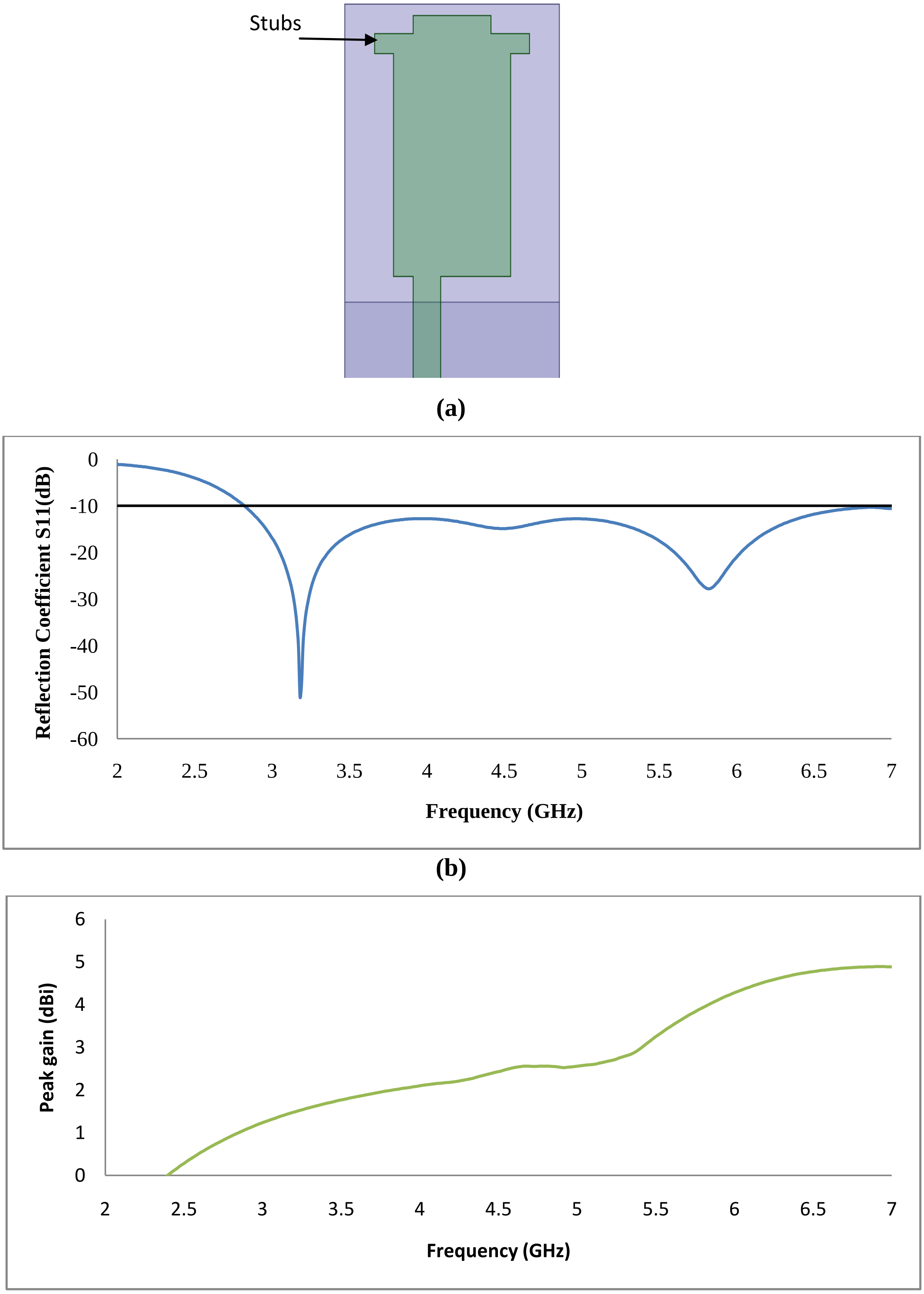
(b)

Fig. 3.17: (a) Reflection coefficient vs frequency for parametric study of th ground plane and (b) Modified ground plane

In order to enhance the wider bandwidth, reasonable gain, radiation efficiency, and radiation patterns, the techniques involving DGS, slot & stubs on the patch and rectangular cut in a ground are utilized and discussed in the following.

3.6.3 Addition of stubs on the patch, slots on the patch & ground and their optimization

All dimensions of the patch, substrate & feed line and position of feed line are kept constant. The stubs on the either side of top of the patch is introduced to increase the electrical path length for shifting the bandwidth at lower frequency with increased gain as shown in Fig. 3.18 (a).



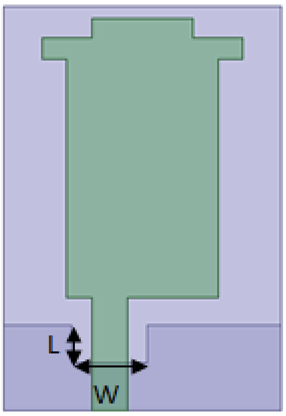
(c)

Fig. 3.18: (a) Introduction of stubs on the patch and (b) Reflection coefficient Vs frequency, (c) Peak gain Vs frequency

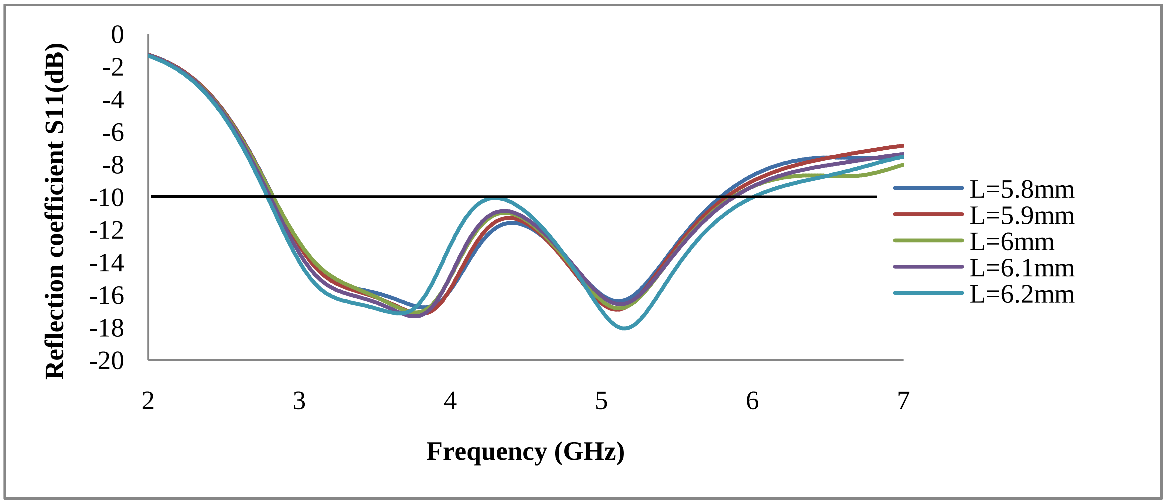
When the stub is added to the top of the patch, it increases the overall electrical path length by which the shift along with the bandwidth of 3900 MHz in lower frequency from 3 GHz to 2.8 GHz has occurred with reflection coefficient of -54 dB as indicated in Fig. 3.18 (b).The peak gain of 4.9 dB is indicated in Fig. 3.18 (c).

Rectangular slot on the ground

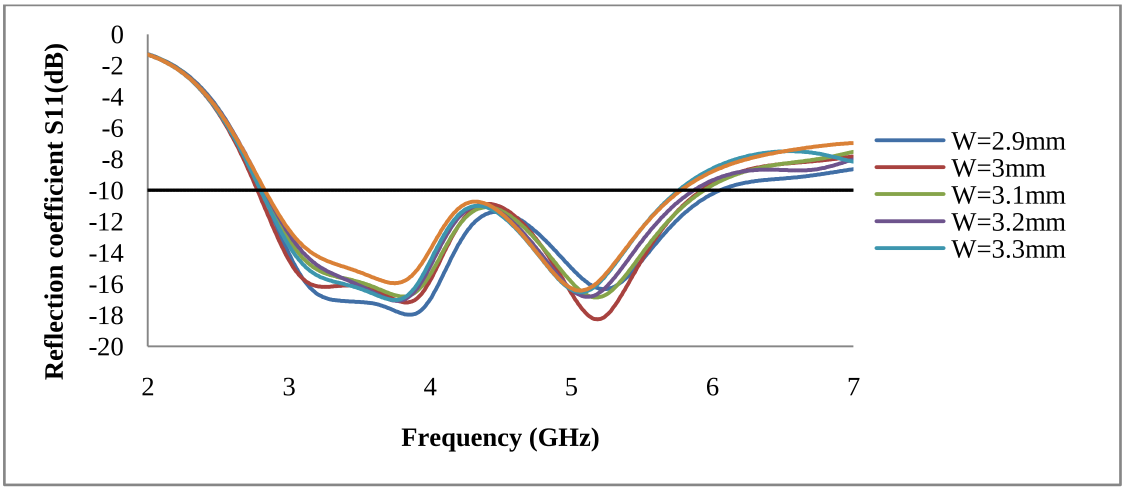
To improve the gain of the antenna, DGS is used. One simple rectangular slot is cut on the ground plane for increasing the gain which results in the decrease in the bandwidth and increase in gain of the antenna. The DGS with rectangular cut on the ground plane is represented as Fig. 3.19 (a)



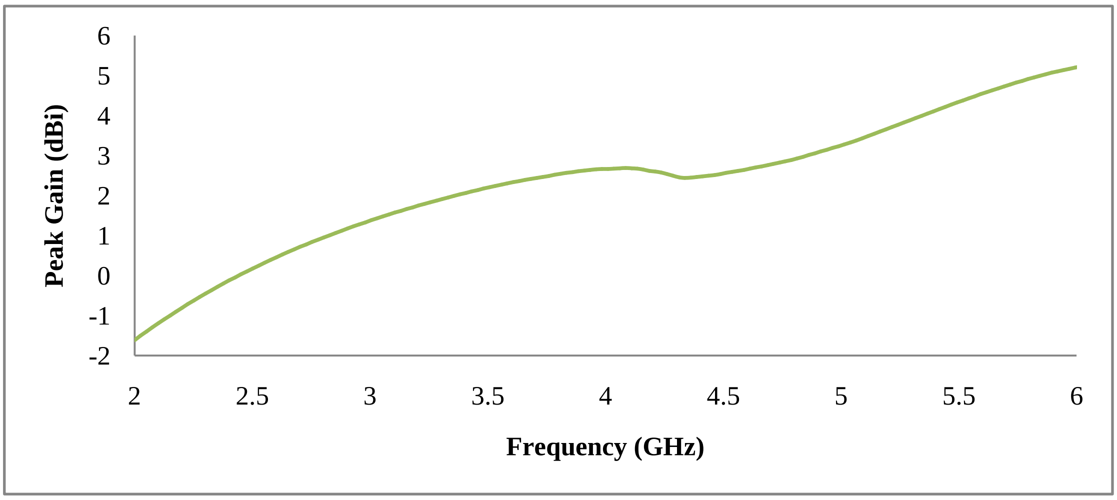
(a)



(b)



(c)



(d)

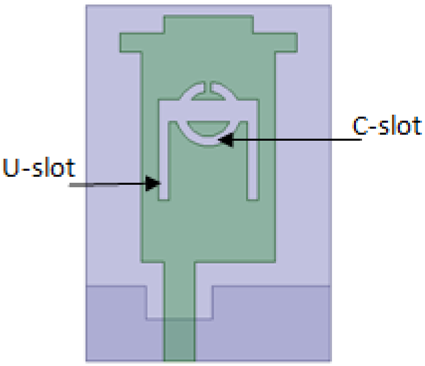
Fig. 3.19: (a) Patch antenna with rectangular slot cut on the ground, (b) Variation in length of rectangular slot Vs frequency and (c) Variation in the width of rectangular slot Vs frequency (d) Peak gain Vs frequency

All earlier dimensions of patch, substrate, partial ground, and feed are kept constant. Now the length (L) of rectangular cut on the partial ground is varied from values 5.8 to 6.2 mm for increase in the gain as shown in Fig. 3.19 (b). However, the bandwidth of 700 MHz is reduced. The optimized length of rectangular cut is found to be 6 mm for the reflection coefficient of -20 dB with decrease in bandwidth of 700 MHz for frequency range from 2.8 to 6 GHz. After optimization of length of the rectangular cut, the width (W) of rectangular cut on the ground is changed from 2.9 to 3.3 mm for increase in gain and the optimized width of rectangular cut is obtained as shown in Fig. 3.19 (c). The peak gain of 5.1 dBi at frequency of 6 GHz, thus achieved is shown in Fig. 3.19 (d).

The next step is to increase the bandwidth. So to achieve this, slots have been cut on the patch which is optimized to get the desired result.

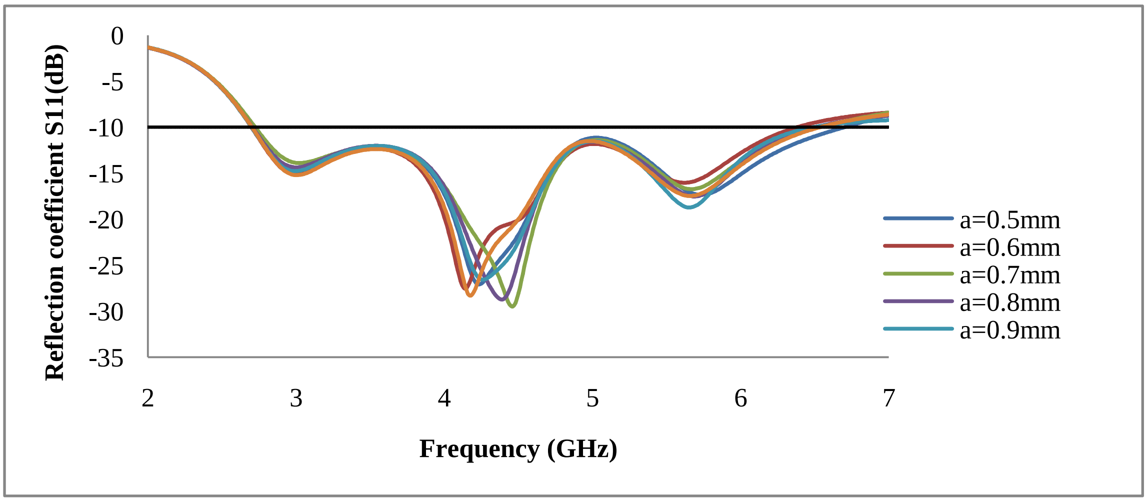
Inverted U-slot and C-slot on the patch

An inverted U-slot and circular C-slot have been cut on the patch to increase the bandwidth with radiation efficiency as represented in Fig. 3.20 (a). Parametric study is carried out to get the desired results.



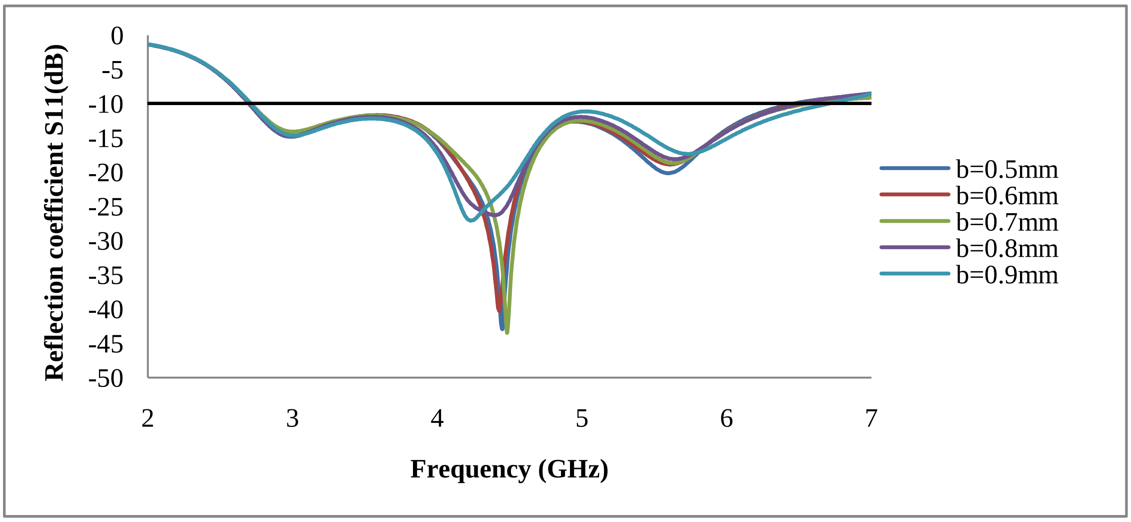
(a)

Keeping earlier dimensions of the patch, substrate, partial ground, feed, and rectangular cut constant. Now, the dimension of the gap (a) in between the circular C- slot is varied from 0.5 to 0.9 mm and the optimized gap value of 0.5 mm in between the circular C-slot is obtained as shown in Fig. 3.20 (b). The reflection coefficient of -25 dB is obtained with the increase in bandwidth of 3770 MHz in the frequency range from 2.73 to 6.50 GHz.



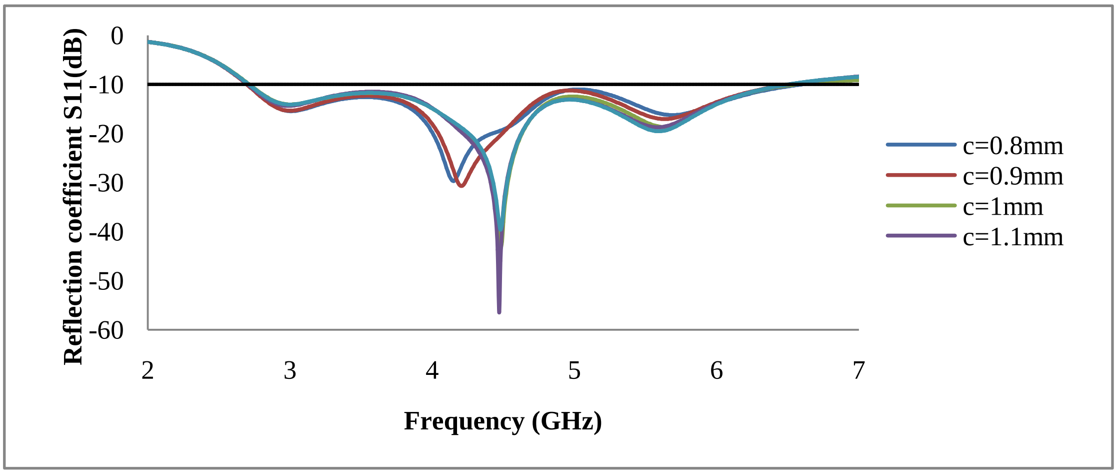
(b)

After optimization of the gap in between the circular C-slot, the radii gap (b) in between the circular C- slot is varied for the values from 0.5 to 0.8 mm and the optimized value of radii gap is obtained 0.7 mm as shown in Fig. 3.20 (c). The reflection coefficient of -45 dB is obtained with the increase in bandwidth of 3770 MHz in the frequency range from 2.73 to 6.50 GHz.

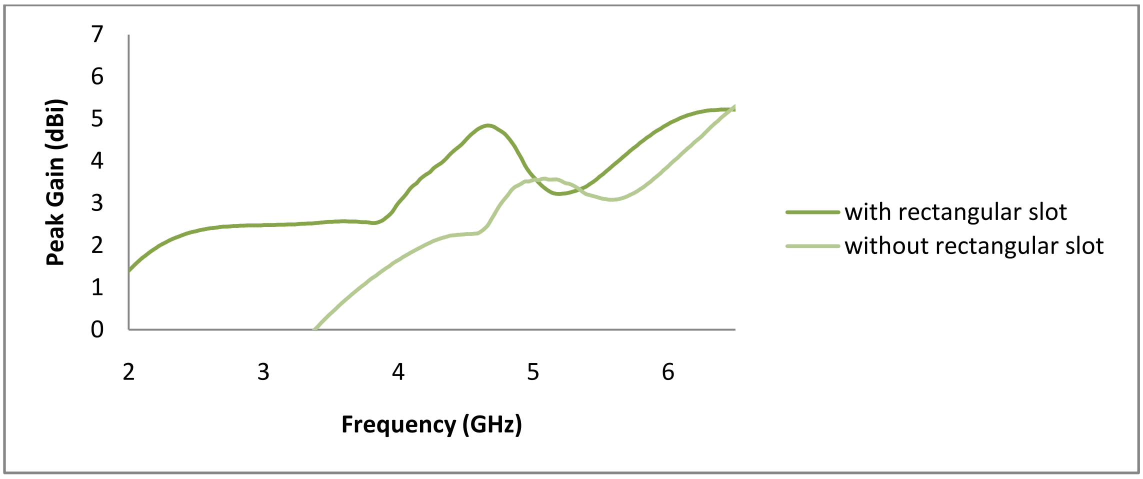


(c)

Keeping the values of gap & radii gap in between circular slot constant, the dimensions of the gap (c) in between the inverted U-slot is changed for the values from 0.7 to 1.1 mm and its optimized value of 1.1 mm as shown in Fig 3.20 (d) is determined. The reflection coefficient of -57 dB is obtained with the increase in bandwidth of 3770 MHz in the frequency range from 2.73 to 6.50 GHz. The peak gain of 5.22 dBi as represented in Fig. 3.20 (e) is observed.



(d)

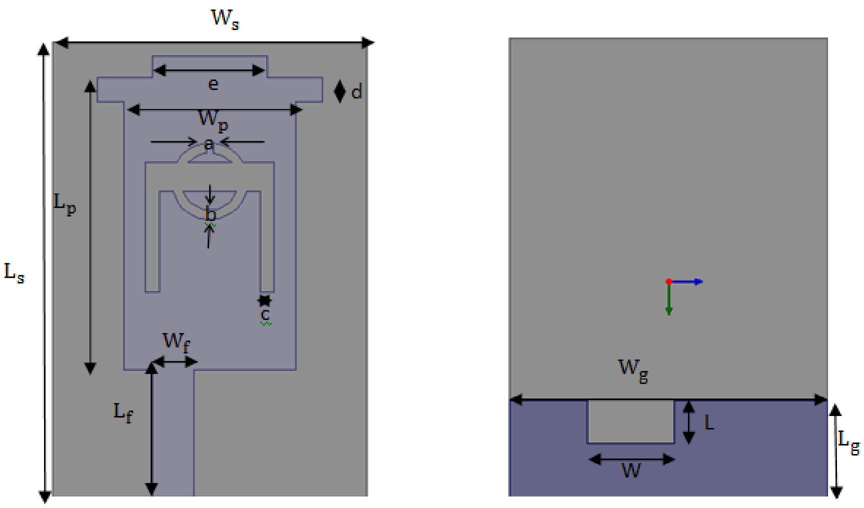


(e)

Fig. 3.20: (a) Modified patch with inverted U-slot and C-slot, and rectangular cut on the ground (b) Reflection coefficient vs frequency parametric study of cut in between C-slot, (c) Parametric study of gap in C-slot, (d) Parametric study of gap in inverted U-slot, (e) Peak gain Vs frequency

Proposed antenna

Above steps are carried out for the development of the proposed antenna i.e. the compact broadband antenna with slots and DGS for wireless application. Proposed antenna is designed and simulated on a copper coated FR4 substrate having dimensions 32 mm×22 mm×1.6 mm and tangent loss of 0.02. Fig. 3.21 depicts the proposed broadband antenna and the optimized design values of the proposed antenna are given in the Table 3.1.



(a) Patch **(b) Ground**

Fig. 3.21: Proposed antenna

Table 3.1: Optimized design values of the proposed antenna (mm)

$L_s = 32$	$L_g = 6.8$	a=0.5
$W_s = 22$	$W_g = 22$	b=0.7
$L_p = 20.5$	$L_f = 9$	c=1.1
$W_p = 12$	$W_f = 2.85$	d=1.7
e=8	L=3	W=6

After optimization of all design values for proposed antenna the simulated reflection coefficient graph showing the significant increase in the bandwidth of 3770 MHz in entire frequency range from 2.73 to 6.51 GHz is represented in Fig. 3.22. The simulated VSWR< 2 in the frequency range of 2.73 to 6.51 GHz for the proposed antenna is shown in Fig. 3.23.

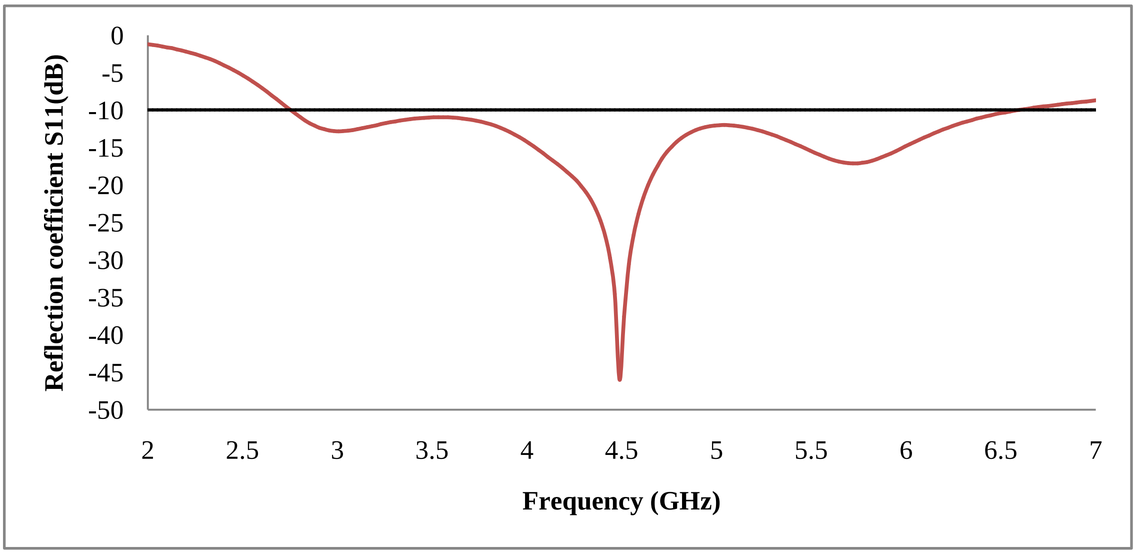


Fig. 3.22 Simulated reflection coefficient Vs frequency for the proposed antenna

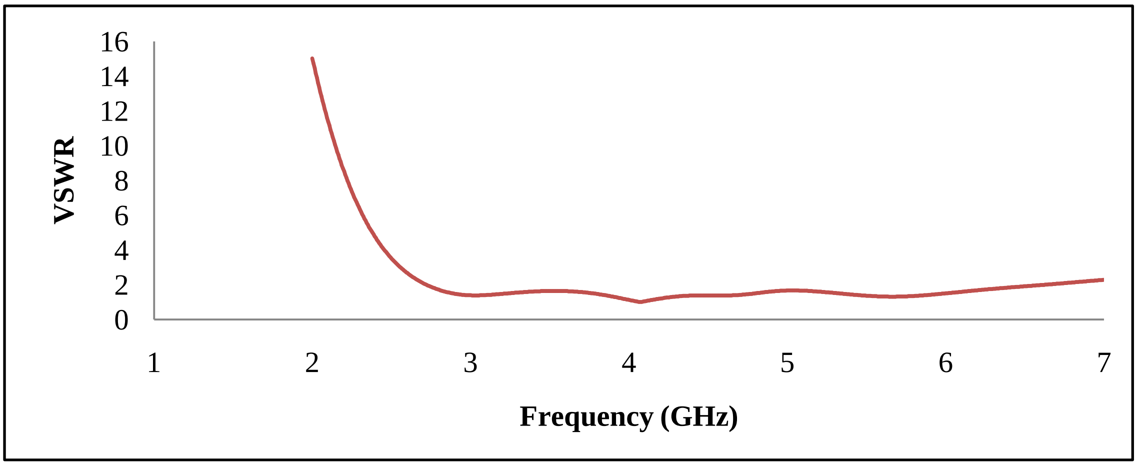


Fig. 3.23 Simulated VSWR Vs frequency for the proposed antenna

3.6.4 Fabrication of the proposed antenna

After the simulation of the antenna in HFSS, next step is the fabrication of the antenna. To fabricate the proposed antenna .dxf file is generated through HFSS which is then converted to Gerber file in PCB prototype EP2002 to make the prototype of the proposed antenna on a copper coated FR4 substrate. Drill bits of different sizes in mm are used to drill, surface inspect, engrave and route the proposed antenna. After the prototype of proposed antenna, SMA connector is used to deliver power to the proposed antenna through feed line. The parameters in terms of reflection coefficient and VSWR for proposed antenna are measured by use of VNA. Fig 3.24 (a) shows the PCB prototype machine where the proposed antenna is fabricated and Fig 3.24 (b) shows the fabricated antenna proposed. The results and discussion are given in next chapter.

(a) **(b)**

Fig. 3.24: (a) PCB prototype machine (b) Fabricated proposed antenna

In the previous chapter material and methods are discussed for use of the development of compact broadband microstrip antenna with DGS for wireless application. Simulation of the proposed antenna has been carried out by HFSS. In this chapter a comparative study of the simulated and measured results has been discussed in detail. The plots of reflection coefficient S_{11} (dB), VSWR, peak gain, radiation efficiency and radiation patterns in the frequency range from 2 to 7 GHz have been presented here.

Comparison is also made between the reference work and the proposed work. Compactness and broadband is an important feature of the proposed work. The simulated and measured results of the proposed antenna show the good agreement between them. The proposed antenna is also compared with the earlier quoted antennas.

Measured results of the proposed antenna

After fabrication of the proposed antenna, measurement of different parameters such as reflection coefficient, S_{11} (dB), VSWR has been carried out for comparing between the simulated and measured results.

Reflection coefficient, S_{11} (dB) and VSWR are measured using VNA. Initially, frequency range has been set in VNA and then port is calibrated to cancel out the environmental losses and other losses. Then the antenna is connected with the VNA through the optical cable and the results have been measured. Fig 4.1 shows the snapshot for measured value of reflection coefficient S_{11} (dB) for the proposed antenna in a frequency range from 2.7 to 6.47GHz with a bandwidth of 3770 MHz.

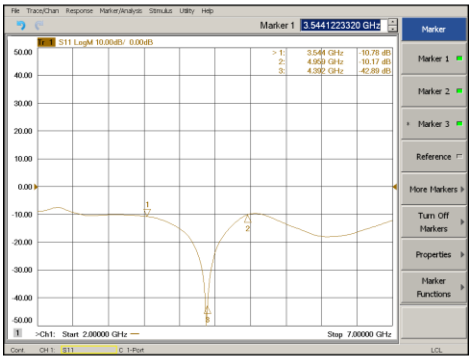


Fig. 4.1: Measured reflection coefficient S_{11} (dB) of proposed antenna using VNA

Fig 4.2 shows the snapshot for measured VSWR of the proposed antenna with value of $0 \leq VSWR \leq 2$ in the frequency range of 2.7-6.47 GHz.

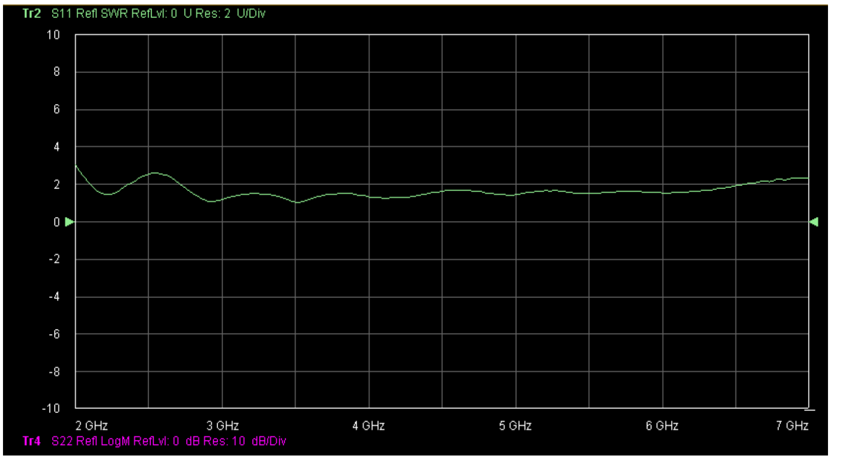


Fig. 4.2: Measured VSWR of the proposed antenna using VNA

The comparison between the measured and simulated results of reflection coefficient S_{11}(dB) < -10dB as shown in Fig 4.3. The measured broad bandwidth of 4500 MHz in the frequency range from 2.7 to 7.2 GHz for reflection coefficient S_{11}(dB) < -10 dB is also shown in the figure whereas on the other hand the simulated bandwidth of 3770 MHz is observed in the frequency range 2.73-6.50 GHz for reflection coefficient S_{11}(dB) < -10 dB. It is clearly observed from the Fig. 4.3 that there is very close agreement between the measured and simulated results of reflection coefficient, S_{11} for the proposed antenna. It is also seen that there is a shift of operating frequency in simulated impedance bandwidth of 3770 MHz due to some fabrication errors. Broad bandwidth is achieved by using reduced ground structure with a slot on the patch. Offset feed also increases the bandwidth of the proposed antenna with the reduced size. Further gain and bandwidth are enhanced by using DGS with a one simple rectangular slot on the reduced ground. Results thus obtained are good enough with this much reduced size of the antenna.

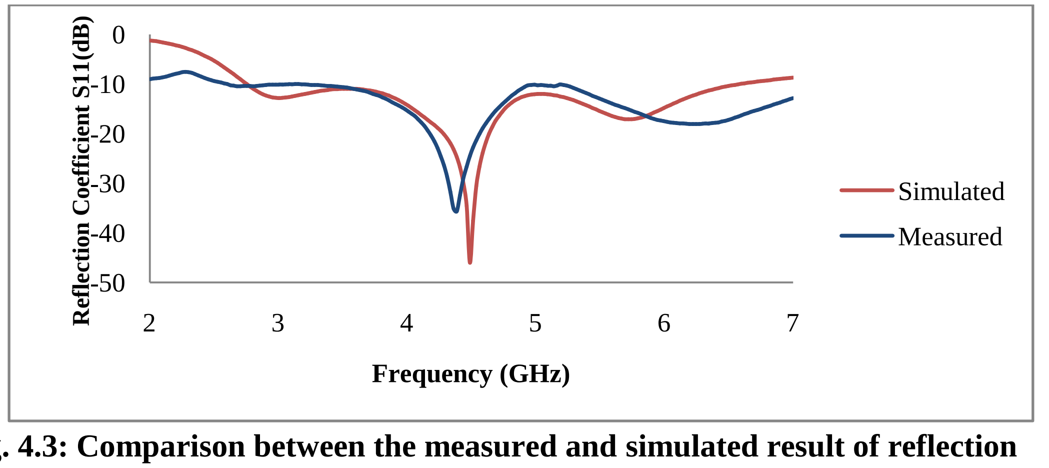


Fig. 4.3: Comparison between the measured and simulated result of reflection coefficient S_{11} (dB) for the proposed antenna

Fig 4.4 shows the comparison between the measured and simulated results of VSWR. The measured and simulated values of VSWR is less than 2 for the entire frequency range from 2.7 to 6.47 GHz (measured) and for frequency range from 2.73 to 6.50 GHz (simulated). It is clear obvious that most of the input power is radiated in frequency bandwidth of 3770 MHz.

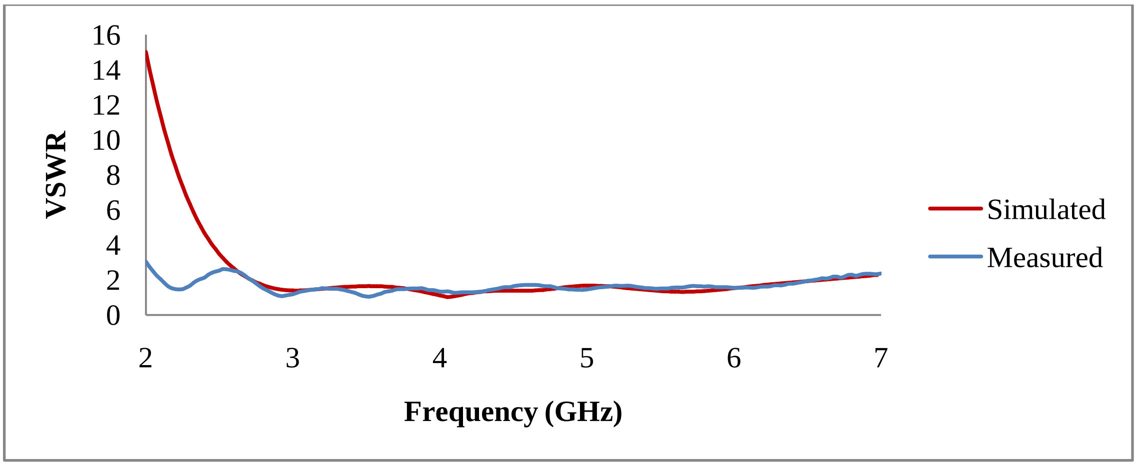


Fig. 4.4: Comparison b/w measured & simulated result (VSWR) proposed antenna

The impedance bandwidth for the proposed antenna has been compared with that of **An *et al* (2018)** which is the reference work as shown in Table 4.1. It is clear from this table that the impedance bandwidth of proposed antenna is greater than that of the reference antenna by 35.7%.

Table 4.1: Comparison of bandwidth of proposed antenna with reference antenna

Analysis	Frequency Range (GHz)	Impedance Bandwidth (%)
An et *al.* (2018) (Reference antenna)	**2.84-5.17**	**58.3**
Proposed antenna	**2.73-6.50**	**94**

Fig 4.5 represents the simulated peak gain of the proposed antenna. It is seen from this graph that the peak gain is found to be 5.22 dBi in frequency range from 2.73 to 6.50 GHz.

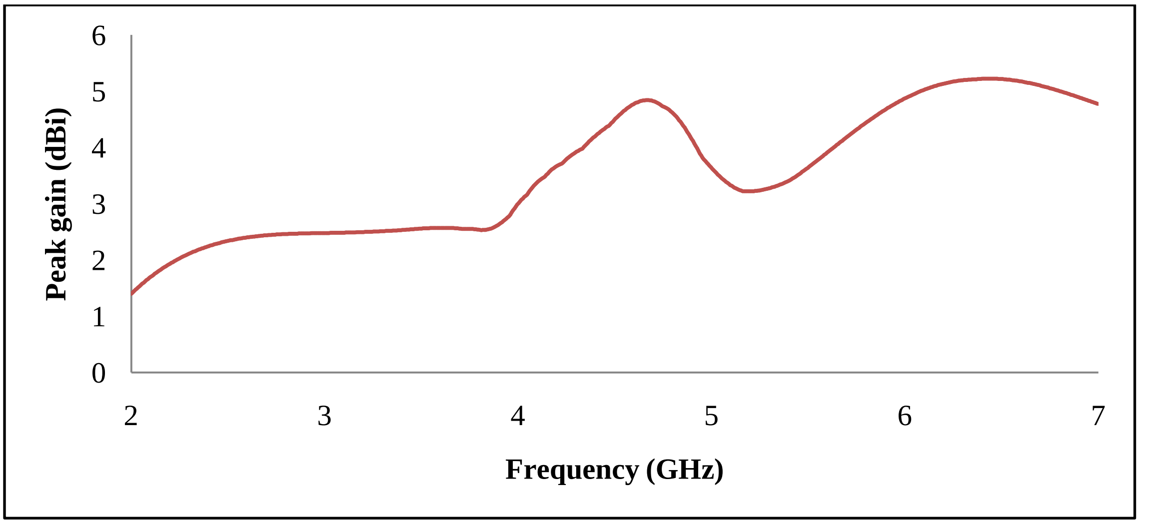


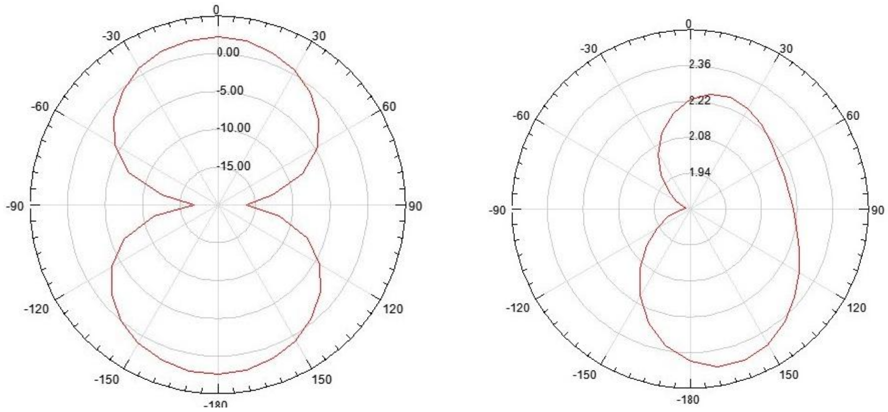
Fig. 4.5: Simulated peak gain of the proposed antenna

Table 4.2 represents the comparison of the gain of the proposed antenna with reference antenna. This comparison shows that the reasonably simulated gain of 5.22 dBi for the proposed antenna is obtained by using single substrate layer having thickness of 1.6 mm. However, the simulated gain of the reference antenna is 6.2 dBi for two substrate layers having thickness of 4.5 mm.

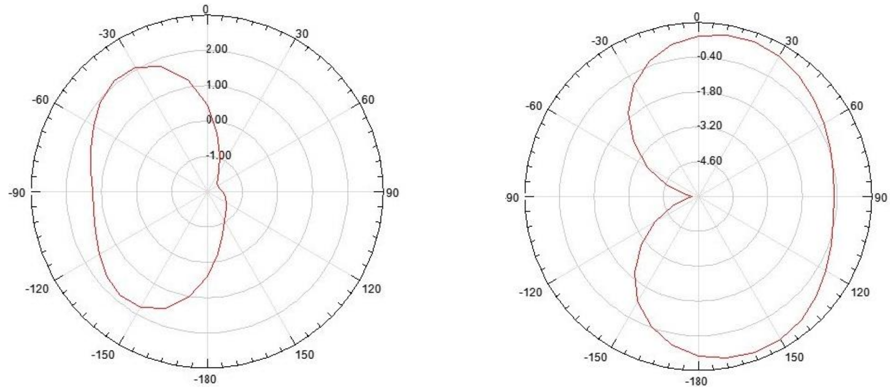
Table 4.2: Comparison of peak gain of proposed antenna with reference antenna

Reference antenna Vs Proposed antenna	Frequency Range (GHz)	Simulated peak gain (dBi)	Substrate layer & Thickness(mm)
An et *al.* (2018)	2.84-5.17	6.2	Double (4.5)
Proposed antenna	2.74-6.50	5.22	Single (1.6)

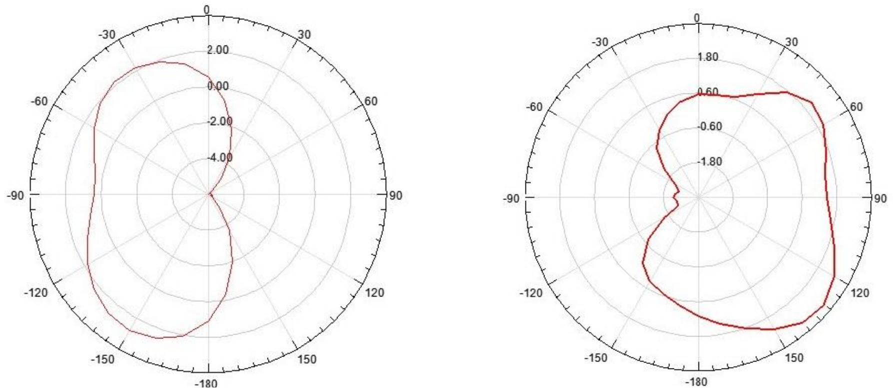
The simulated radiation patterns (**E**-plane and **H**-plane) for proposed antenna at different frequencies i.e. 2.74, 4.06, 5.75, and 6.50 GHz are shown in Fig. 4.7.



(a)



(b)



(c)

Fig. 4.6: (a) E-plane & H plane at 2.75 GHz, (b) E-plane & H plane at 4.06 GHz (c) E-plane & H- plane at 5.60 GHz

The comparison of the parameters in terms of bandwidth, peak gain, size, substrate, and cost for the proposed antenna and earlier designed antennas are shown in

Table 4.3. It is clearly seen from the table that the broad bandwidth of the proposed antenna with reasonable gain is obtained as 94% and its size is reduced to $0.42 \times 0.29 \times 0.02\ mm^3$, which adds the novelty in this work. The summary and conclusion with future scope is given in the following chapter.

Table 4.3: Comparison of the proposed antenna with previously designed antennas

Published antenna vs proposed antenna	**Bandwidth (%)**	**Peak gain (dBi)**	**Size (λ at center frequency)**	**Substrate**	**Cost**
Khan &Chatterjee (2016)	31.0	N.A.	0.65×0.65×0.09	FR4	Low
Fan et *al.* (2017)	34.4	12.5	1.14×1.62×0.076	Rogers	High
Lin & Chen (2017)	31	14.1	1.78×1.78×0.07	Rogers	High
Liu et *al.* (2017)	30	7.8	0.46×0.46×0.06	Rogers	High
Hicho et *al.* (2015)	55.6	10.2	0.84×0.84×0.098	PVC	Medium
Malekapoor & Jam (2016)	86.5	10.6	1.69×2.70×0.135	FR4	Low
An et *al.* (2018)	58.3	6.2	0.84×0.68×0.06	FR4	Low
Proposed antenna	**94**	5.22 (Simulated)	**0.42×0.29×0.021**	**FR4**	**Low**

Chapter 5 SUMMARY AND CONCLUSIONS

The proposed compact broadband antenna for wireless applications is designed with the help of TLM model and equations, simulated in HFSS, fabricated in PCB prototype EP2002 machine, and measured using VNA (for reflection coefficientS_{11} in dB and VSWR) and anechoic chamber (radiation pattern). Summary of the proposed work is as follows:

The first chapter gives an introduction about MSA, design of MSA with different shapes, a brief overview of broadband antenna, a simulator where the antenna is simulated, and a brief idea of plan of work.

In the second chapter i.e. review of literature, previous work done in the area of MSA, wideband antenna, slot antenna, DGS antenna and broadband antenna has been reviewed.

The third chapter gives the fair idea about what kind of material and methods is used in designing of the proposed antenna such as methods for designing patch of antenna using TLM, different kinds of feeding techniques, HFSS simulation and fabrication using PCB prototype machine and measurement using VNA. Designing process started from conventional rectangular MSA to a proposed compact broadband patch antenna with DGS for wireless communication has also been discussed in this chapter. Compact broadband patch antenna has been discussed in details. Comparison between the measured and simulated results is shown in this chapter. The proposed work is also compared with the previous reported work.

Conclusions

- The MSAs having wide/broad bandwidth in the field of wireless applications have been studied
- Reduction in ground, offset in feed and an inverted U-slot unite with C-slot is used to enhance the bandwidth of the proposed antenna
- Defective Ground Structure (DGS) in the form of one simple rectangular slot is used to enhance the gain and to reduce the size of the proposed antenna.

- Fabrication of the proposed antenna is done on the PCB prototype machine with due care. SMA connector is soldered at the feeding part with care such that no extra metal is added to the proposed antenna.
- VNA is calibrated carefully to avoid EM interference and other environmental losses for measuring reflection coefficient and VSWR.

Future scope

Future scope for the researcher of this work can be exploited as

- Various techniques can be explored further to reduce the size of the proposed antenna such as by using CSRR etc.
- Performance of the proposed antenna in terms of bandwidth can be improved further by using different kind of feeding techniques.
- Gain of the proposed antenna can be increased further by using different kinds of substrate.

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ABSTRACT

With the rapid growth of wireless communications in recent years, users need multiple frequency bands at the same time to access different services such as voice video and data. Therefore, it has become to have compact microstrip antenna (MSA) with a wide band to avoid employing multiple antennas to fulfil requirement of the users. The MSA is a revolution in the field of wireless applications due to its low cost, ease of installation, performance and low profile structure which make it a high quality contender. for many communication equipment.

The main objective of this proposed work is to develop a compact broadband microstrip antenna with DGS for wireless applications in the frequency range of 2-7 GHz. The proposed antenna is designed using TLM model and is simulated and optimized using HFSSv.15 with a centre frequency of 4GHz. Proposed antenna is used to operate at the frequency range of 2.73-6.50 GHz in wireless applications like WiMAX (3.6 GHz), Hi-LAN (5.15-5.35 GHz), WLAN IEEE802a (5.2 GHZ), and DSRC for a car to car communication (5.850-5.925 GHz). A 6-6.50 GHz might be used for future 5G communication and other application as CCTV, Camera and Cmax. The proposed antenna is fabricated on a FR4 substrate having thickness 1.6 mm and loss tangent of 0.02. The fabricated antenna has dimensions $32\times22\times1.6$ mm^3which makes it compact in nature. The parameters in terms of reflection coefficient and VSWR for the proposed antenna (fabricated) are measured and compared with the simulated ones, which show good agreement. The proposed antenna is also compared with the earlier designed antennas. The measured broad bandwidth with reflection coefficient below -10 dB is found to be 4500 MHz in the frequency range from 2.70- 7.2 GHz. Simulated peak gain of 5.22 dBi and radiation efficiency of 90-98% for the proposed antenna in the frequency range from 2.73 - 6.50 GHz are observed. The proposed antenna has a stable radiation pattern in both E and H planes.

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शोध का शीर्षक : **" COMPACT BROADBAND MICROSTRIP ANTENNA WITH DGS FOR WIRELESS APPLICATIONS"**

सलाहकार : **डॉ। आर.पी.एस. गंगवार**

सार

हाल के वर्षों में वायरलेस संचार के तेजी से विकास के साथ, उपयोगकर्ताओं को विभिन्न सेवाओं जैसे आवाज वीडियो और डेटा तक पहुंचने के लिए एक ही समय में कई आवृत्ति बैंड की आवश्यकता होती है। इसलिए, उपयोगकर्ताओं की आवश्यकता को पूरा करने के लिए कई एंटेना को नियोजित करने से बचने के लिए एक विस्तृत बैंड के साथ कॉम्पैक्ट माइक्रोस्ट्रिप एंटीना (एमएसए) हो गया है। एमएसए अपनी कम लागत, स्थापना में आसानी, प्रदर्शन और कम प्रोफ़ाइल संरचना के कारण वायरलेस अनुप्रयोगों के क्षेत्र में एक क्रांति है जो इसे उच्च गुणवत्ता का दावेदार बनाता है। कई संचार उपकरणों के लिए।

इस प्रस्तावित कार्य का मुख्य उद्देश्य 2-7 गीगाहर्ट्ज़ की आवृत्ति रेंज में वायरलेस अनुप्रयोगों के लिए डीजीएस के साथ एक कॉम्पैक्ट ब्रॉडबैंड माइक्रोस्ट्रिप एंटीना विकसित करना है। प्रस्तावित एंटीना को टीएलएम मॉडल का उपयोग करके डिज़ाइन किया गया है और 4 गीगाहर्ट्ज़ के केंद्र आवृत्ति के साथ HFSSv.15 का उपयोग करके सिम्युलेटेड और अनुकूलित किया गया है। प्रस्तावित एंटीना का उपयोग वाईमैक्स (3.6 गीगाहर्ट्ज), हाय-लैन (5.15-5.35 गीगाहर्ट्ज), डब्ल्यूएलएएन आईईईई802 ए (5.2 गीगाहर्ट्ज), और डीएसआरसी से कार संचार के लिए वायरलेस अनुप्रयोगों जैसे 2.73-6.50 गीगाहर्ट्ज की आवृत्ति रेंज में संचालित करने के लिए किया जाता है। (5.850-5.925 गीगाहर्ट्ज़)। एक 6-6.50 गीगाहर्ट्ज भविष्य के 5 जी संचार और अन्य एप्लिकेशन के लिए सीसीटीवी, कैमरा और सीमैक्स के रूप में उपयोग किया जा सकता है। प्रस्तावित एंटीना एक FR4 सब्सट्रेट पर बना है जिसकी मोटाई 1.6 मिमी है और 0.02 का नुकसान स्पर्शरेखा है।

निर्माण किया हुआ एंटीना के आयाम 32 × 22 × 1.6 मिमी ^ 3 हैं जो इसे प्रकृति में कॉम्पैक्ट बनाता है। प्रस्तावित एंटीना के लिए प्रतिबिंब गुणांक और वीएसडब्ल्यूआर के संदर्भ में पैरामीटर (निर्माण किया हुआ) को मापा जाता है और अनुरूप लोगों के साथ तुलना की जाती है, जो अच्छा समझौता दिखाते हैं। प्रस्तावित एंटीना की तुलना पहले से डिज़ाइन किए गए एंटेना से भी की जाती है। परावर्तन गुणांक -10 डीबी के साथ सिम्युलेटेड व्यापक बैंडविड्थ 2.70-6.47 गीगाहर्ट्ज से आवृत्ति रेंज में 3770 मेगाहर्ट्ज पाया जाता है। २.३-६.५० गीगाहर्ट्ज से आवृत्ति रेंज में प्रस्तावित एंटीना के लिए ५.२२ डीबीआई का विकिरणित शिखर लाभ देखी जाती है। प्रस्तावित एंटीना में ई और एच दोनों सतह में एक स्थिर विकिरण पैटर्न है।

(आर.पी. एस. गंगवार)
सलाहकार

(भरत पंत)
लेखक